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ORIGINAL ARTICLES

*FLOATING HABIT IN RICE

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(With Plates I and II)

INTRODUCTION

AMONG the thousands of rice varieties cultivated in India and Burma there is a particular class known as deep-water rices which is chiefly to be found in Bengal, Assam and Burma. In the tracts where these rices are grown, they are usually sown broadcast during March-May and harvested in December-January. With the onset of the monsoon in June, the areas where the rices are grown are flooded. The water rises gradually in the fields, reaching to a height of even 20 ft. in some cases. The rice grown under such conditions has to keep pace with the water rise, and this it generally does, when the latter is gradual and not too rapid or sudden. Botanical study of the deep-water rices has not been made for a long time because of the inherent difficulties. Recently, however, a special research station for such study has been opened at Habiganj, Assam, financed by the Imperial Council of Agricultural Research.

The typical deep-water conditions, such as those existing in Bengal and Assam, are not present in Madras. In some places, however, the water accumulates to depths of more than 5-6 ft., but this condition does not persist for a sufficiently long time. By experience the cultivators have found that some of the ordinary varieties are able to stand this moderate and temporary flooding. *Akkullu* of the Godavari, *vadansamba* of Tanjore and *kuttadan* of Malabar are some of the varieties cultivated by ryots under these conditions. The maximum height to which these varieties are known to grow is about 8·10 ft. whereas the senior author of this paper has seen the typical deep-water rice growing to a height of even 20 ft. in Habiganj (Plate I, fig. 1). Certain of the deep-water rices of Bengal were introduced in Madras some years ago for trial. These are now included in the type collections of the Paddy Breeding Station, Coimbatore. The present paper deals with the genetic investigations with one of these types, T 599, started in 1933.

CHARACTERISTICS OF DEEP-WATER RICES

The main difference among the several deep-water rices grown in Assam is their differential response to varying depths of water [Majid, 1936]. Presumably, associated with their deep-water habit are some morphological differences which are characteristic of these rices. The stems do not grow quite erect but rather zig-zag under the water and have a tendency to crawl on the surface above the water level, and this peculiar habit is responsible for their being called ' floating rices '. Very often tillers and roots are produced at the nodes higher up from the base of the stem (Plate I, fig. 2). Though these characters are pronounced only when the deep-water conditions are present, they can still be made out when grown under less suitable conditions, where there is not sufficient water to support the growing shoots, in which case they come down flat on the ground, particularly at the later stages. One special characteristic of the deep-water rices observed in Coimbatore is their rate of growth, which is comparatively greater than that of ordinary rices, due evidently to their inherent tendency to keep pace with the rapid rise in the water level obtaining in their natural habitat. Among hundreds of varieties grown side by side in the seed-beds at the Paddy Breeding Station, Coimbatore, it is always an easy matter to pick out the deep-water rices by their taller growth (Plate I, fig. 3). The growth of these seedlings is fairly rapid for some time after transplantation and it gradually slows down later in the absence of sufficient depths of water. The increase in height after transplanting is brought about mainly by the elongation of the internodes close to the ground. A similar response is shown even by ordinary rices which, under conditions of high initial fertility in the soil, elongate their lower internodes more than under normal conditions, resulting in premature lodging [Ramiah *et al.*, 1934]. The root-system of the deep-water rice has been found to be not as well developed as in ordinary rices of similar duration. Under the flooded conditions the lack of an efficient root-system is probably made up by the roots formed at the higher nodes, which according to Majid [1936] do supplement the normal roots in the supply of nutrition to the plant.

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*Paper contributed to the Indian Science Congress, 1937

In Coimbatore these rices are first sown in seed-beds and later transplanted, as in the case of ordinary rices, but the *bunds* of the fields in which they are planted are specially raised to impound more water than is usual, say, up to two feet. Even under such conditions, which are not anything like what occur in Assam or Bengal, the special characteristics of the deep-water rices become apparent, sufficient to distinguish them from the rest.

MATERIAL FOR THE STUDY

One of the deep-water rices, T 599, which has been grown in Coimbatore for some years and found to be pure for the characteristic habit, was crossed with an ordinary type, T 300, with a typical compact habit of growth (Plate II, fig. 1). T 599, though normally grown under ordinary conditions as those for other rices at the Paddy Breeding Station, nevertheless shows its capacity to respond to deep-water conditions when such are provided. Potted plants were suspended under water in a well and the depth of water gradually increased, when it was found that the plants grew up with the rise in water level and reached nearly 12 ft., in contrast to the maximum height of only 5 or 6 ft. obtained when planted under ordinary field conditions. This characteristic response of deep-water rice could not be made use of for differentiating deep-water and ordinary rice in our study of the hybrid between these types

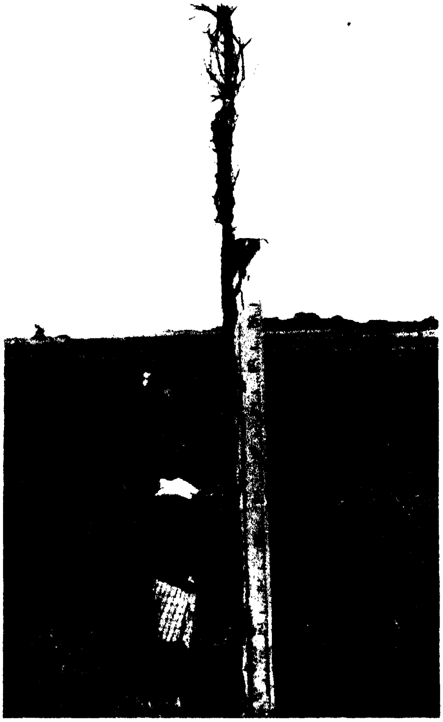

FIG. 1. A typical floating rice plant grown in Habiganj, Assam

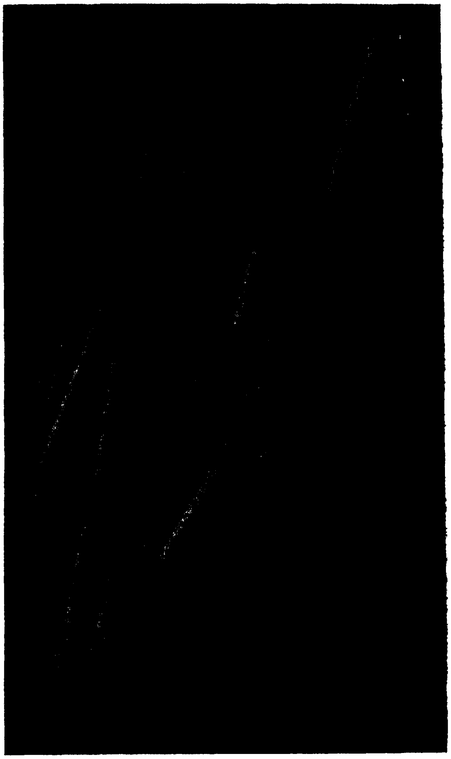

FIG. 2. A plant of T 599 showing tillering and rooting

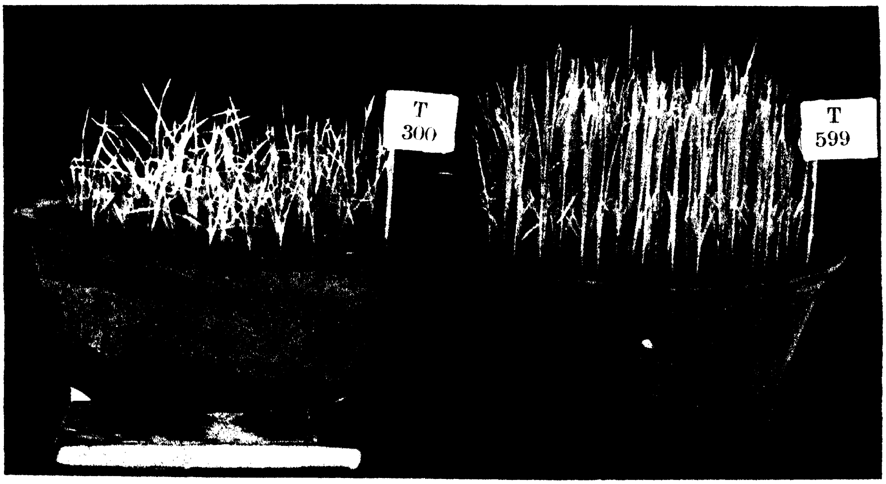

FIG. 3. Seedlings of T 300 and T 599—three weeks old

PLATE I.

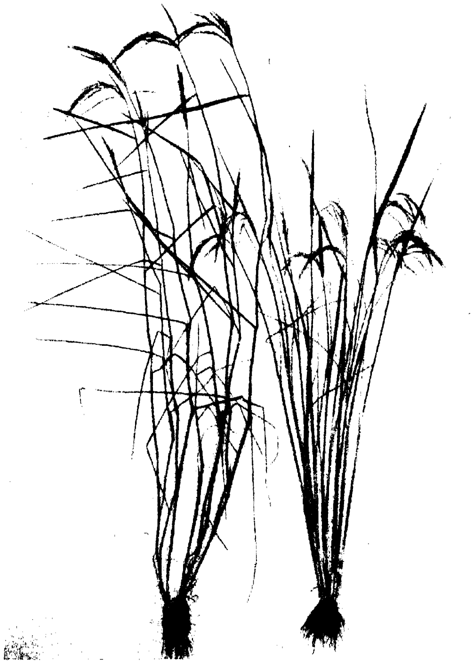

FIG. 1. Typical plants of T 599 and T 300

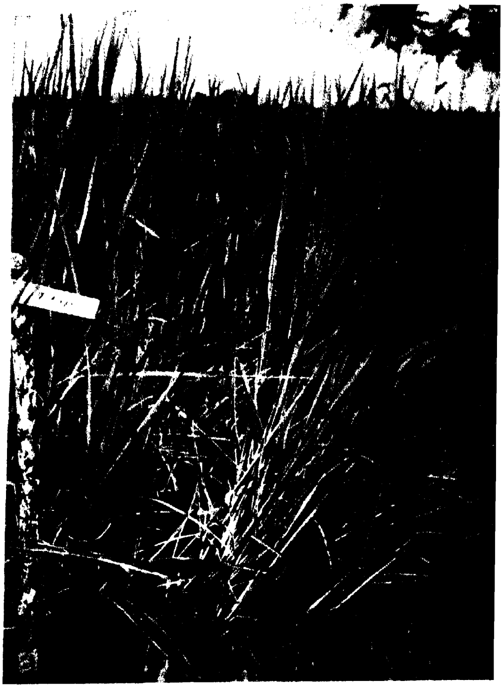

FIG. 2. T 599, just before flowering phase

and its progenies as it was found impossible to provide the deep-water conditions artificially at Coimbatore. However, other characters which will be described later, typically distinguishing the two types, were employed for the study of the F_1 and later populations.

F_1 AND F_2 CHARACTERS

According to the usual practice adopted in Coimbatore, the hybrid seeds along with the parents were first sown in seed-pans and the seedlings later transplanted in a field, with the parents on either side of the hybrid. The F_1 characters in comparison with those of the parents are given below :—

Type No.	Height of plant (ft.)	Flowering duration (days)	No. of ears* per plant	Habit
T 300 . . .	3·3±0·06	95·4±0·46	37·5±1·18	Normal, compact tillers
T 599 . . .	5·2±0·06	103·1±0·25	27·2±1·42	Floating, not compact
F_1 . . .	4·5±0·04	105·1±0·34	31·2±2·10	Normal

* The very large number of ears per plant is due to the wide spacing given per plant namely, 2 ft. × 2 ft.

The F_1 is more or less intermediate in height between the parents, the small increase over the mean of the parents being probably due to heterosis. In flowering duration, lateness of T 599 is apparently dominant. With regard to habit, the F_1 was normal, there being no indication of the floating habit at all even in the final stages. Though the plants were grown only under ordinary conditions, T 599 exhibited the characteristic floating habit just before the commencement of the flowering phase ; the tillers on the outer zones of each clump started trailing on the water surface and the whole plant showed a tendency to topple over (Plate II, fig. 2). At a still later stage all the tillers came down flat on the surface of the water level.

In 1935 an F_2 generation of about 440 plants was raised under ordinary conditions only. There was segregation for the floating habit (Plate II, fig. 3) and all the plants resembling T 599 were put into one class, grouping the rest as normal. The ratios obtained were :

	Normal habit	Floating habit	Total
Observed	412	28	440
Expected on a 15 : 1 ratio .	411·5	27·5	440

The floating habit is evidently controlled by duplicate recessive genes, $\mathbf{ef_1}$ $\mathbf{ef_2}$.

F_3 RESULTS

To make sure of the F_2 segregation for the floating habit, 10 rows of plants from the F_2 comprising about 190 plants were carried forward and the F_3 generation raised from them. Since the idea was only to confirm the F_2

ratios, the size of each of the F_3 families was restricted to 75 plants only. Except in certain of the families mentioned below no detailed counts were taken beyond recording whether each family was pure or segregating for the habit.

No. of F_3 families grown	F_2 character	F_3 behaviour
177 . . .	Normal habit .	82 pure normal habit (82·6), 95 segregating for habit (94·4) (Both 3 : 1 and 15 : 1 ratios)
14 . . .	Floating habit .	Pure floating

The expected pure and segregating families on the basis of duplicate factor hypothesis (figures in brackets) agree with the actuals closely. The ratios obtained in some of the segregating families where individual counts were taken are given below :—

Family No.	Normal habit	Floating habit
3157	58	16
3164	56	14
3176	49	23
3190	51	13
Total . . .	214	66
Expected on 3 : 1	210	70

Family No.	Normal habit	Floating habit
3156	68	4
3161	67	6
3169	61	4
3180	67	5
Total . . .	263	19
Expected on 15 : 1	264·4	17·6

Among the segregating F_3 families there are thus two kinds of segregation as would be expected, and the F_3 behaviour confirms the observations made in F_2.

ASSOCIATION OF FLOATING HABIT WITH OTHER CHARACTERS

Besides the observations for the floating habit for which the cross was mainly intended, the F_2 generation was also studied for various other characters as nature of tillering, flowering duration and plant height.

Nature of tillering.—Rice varieties vary very much in regard to their nature of tillering ; in some, the tillers remain erect and compact and in others they are spreading and open, the former being sometimes a simple recessive [Ramiah, 1930]. In the present cross, T 300 has a compact tillering while the floating rice T 599 has an open tillering. There was a clear segregation in the F_2 for this character and while the compact type was easily made out, there was a good deal of variation among the open types. Actual counts of the two types gave 218 compacts to 218 of the rest. Evidently the segregation for this character is not simple in this cross. The classification of the F_2 for the nature of tillering along with the floating habit is given below :—

	Normal habit		Floating habit	
	Compact tillering	Rest	Compact tillering	Rest
	198	210	20	8
Expected on independence of the two characters	204	204	13·5	13·5

$\chi^2 = 6 \cdot 6$, P between $0 \cdot 05$ and $0 \cdot 02$

On a test of independence the deviation from the expected is definitely significant in the case of the floating group, i.e. a larger number of plants with the floating habit tends to be compact in tillering. It must be noted in this connection that there was no difficulty in distinguishing the habit, floating or normal, along with the nature of tillering, loose or compact. The nature of tillering can be identified even in the earlier stages as the plants grow, while the floating habit, under the conditions in which the plants were grown in Coimbatore, is best made out just when the plants are nearing shot-blade stage. At this time, in plants with the floating habit the outermost tillers in the clone begin to trail on the ground and later the whole plant leans out, the tillers not being able to stand erect. In the floating type the plant with the compact tillering leans out as a whole and all the tillers lie together, whereas in the plant with the loose tillering the leaning over of the tillers happens in all directions and they are thrown far apart, with the result that the plant presents an outspread appearance. In the plants with the normal habit the tillers may remain compact or open but they never trail on the ground and the plants do not get the tendency of falling over.

Plant height.—T 300 was short while T 599 was tall and the F_1 was more or less intermediate between the two. The F_2 was varying a great deal for plant height. Though actual measurements of individual plants were not taken, they were classified into three groups—tall, medium and short—by eye-judgment and the following ratios were obtained :—

Tall	Medium	Short	Total
187	199	52	438

The classification of height along with the habit gave :

Normal habit			Floating habit		
Tall	Medium	Short	Tall	Medium	Short
175	189	47	12	10	5
Expected on independence of the two characters :					
175·5	186·7	48·8	11·5	12·3	3·2

$\chi^2 = 1 \cdot 56$, P between $0 \cdot 95$ and $0 \cdot 90$

It shows that both the characters, plant height and plant habit, which are controlled by different mendelian genes are independent and there is no sort of interaction among them. The significance of this is discussed later, *Flowering duration.*—T 599 was definitely later than T 300 and the F_1 was also showing complete dominance of lateness. The flowering dates of individual plants were noted every alternate day in the F_2 generation and the frequencies are given in the table below :—

Frequencies of flowering duration—days after sowing—in F_2

Days	70	72	74	76	78	80	82	84	86	88	90	92
Normal . .	10	9	14	23	13	5	3	4	7	1	0	4
Floating . . .	3	0	2	3	3	...	...	1	...	...	1	...
Total .	13	9	16	26	16	5	3	5	7	1	1	4

Days	94	96	98	100	102	104	106	108	110	112	114	Total
Normal . . .	11	47	12	82	64	47	39	7	8	0	2	412
Floating . . .	1	1	1	6	1	3	...	...	1	1	...	28
Total .	12	48	13	88	65	50	39	7	9	1	2	440

If the frequencies are divided at the minimum frequency point, say, 90 days, and totalled, we get :

	Early	Late	Total
	102	338	440
Expected 1 : 3 ratio	110	330	440

$\chi^2=0\cdot773$, P between $0\cdot7$ and $0\cdot8$.

Evidently lateness here is a simple dominant to earliness. The distribution of the earlies and lates is, however, not the same in the two groups, normal and floating habit. There is an excess of earlies in the floating group. Applying the test of independence, we get $\chi^2=9\cdot08$ and P less than $0\cdot01$, which means that the two characters, flowering duration and habit, are not genetically indepdendent.

	Normal habit		Floating habit		Total
	Late	Early	Late	Early	
	323	89	15	13	440
Expected on 45 : 15 : 3 : 1 ratio	309·4	103·1	20·6	6·9	440

Evidently one of the genes controlling habit and the gene controlling flowering duration are linked and there is crossing-over to the extent of 30 per cent calculated by the 'maximum likelihood' method. Which of the duplicate genes for habit is linked with duration gene has to be investigated.

DISCUSSION

The investigation here recorded definitely proves that the floating habit, characteristic of one of the deep-water rices grown extensively in Bengal and Assam, is a mendelian recessive controlled by two duplicate genes. The detailed examination of the F_2 of a cross between a floating rice and a normal rice for some of the other important characters besides the habit has shown some interesting genetic associations which are of great significance in practical breeding. A rice with a compact nature of tillering is always to be preferred to those with an open, loose type of tillering, as the former does not usually lodge at the time of harvest to the same extent as the latter. Although the question of lodging of the straw is not an important consideration in the case of the floating rices, it will still be an advantage to introduce the compact nature of tillering in them by suitable crosses. This might facilitate ease in harvest and it is possible that with a compact nature of tillering a larger number of seedlings can be planted per acre and this should materially add to the final yield.

Among the deep-water rices in Bengal and Assam there are different types suited to the different depths to which the water is expected to rise. This, in all probability, is mainly a question of the height (a mendelian character) up to which the plant is capable of growing. Since this investigation has shown that there is no genetic association between plant height and the floating habit, it should be a simple matter to breed out floating types of different heights by suitable crossings with rices of normal habit. One of the complaints in certain parts of Madras, where there is scarcity of fodder, is that some of the improved types recommended by the Agricultural Department do not produce enough straw. In the deltas where the rice fields are cultivated mostly by tenants for a portion of the produce, the tenants get only a small fraction of the grain but the bulk of the straw. It is by selling the surplus straw that the tenant can expect to get something out of the land and thus the quantity of straw produced per acre is certainly an important factor. Other things being equal a taller-growing rice should give more straw than a shorter one. The inherent nature of the more rapid growth of the floating rices can be made use of to increase the straw yield of the ordinary rices by suitable crosses. In fact some pure breeding types with longer straw and hence larger amount of straw than the parent T 300 have been extracted out of this cross. Wherever the yield of straw is sought to be increased in rice, the best way of doing it would appear to be to cross it with a floating rice and select suitable types from the F_2 onwards.

Though no detailed analysis was made of the F_2 with regard to the variations in grain size in this cross, the results would seem to indicate that the grain size, again a mendelian character, is independent of the floating habit. Floating rices are all generally coarse grained. Parent T 599 is also coarse, whereas T 300 is a fine grain. Pure-breeding fine rice types, like T 300, but with the floating habit have been extracted from this cross.

Lastly this cross has also shown the possibility of getting floating types with different flowering durations which is important economically. Though the genes controlling flowering duration may be different in different rices, the results obtained from this cross indicating a linkage between duration and floating habit would appear to demonstrate the possibilities of breeding specially early types in floating rices by suitable crosses.

The few floating rices available in the Coimbatore collections have not shown much variation in their flowering duration. Moreover, unlike in their original home (Bengal), they are planted in Coimbatore much later in the season, July-August, instead of April-May and this should by itself reduce the duration considerably. Duration is controlled by several genes [Ramiah, 1933] and there must be a big variation in the flowering duration among the floating types cultivated in Bengal and Assam. It would be interesting to undertake crosses between a normal type and floating types of different durations to get more definite information on the genetic linkage of floating habit and duration.

A certain number of pure types have now been extracted from the homozygous F_3 families of this cross showing various combinations, like early and late, tall and short, open and compact tillering and coarse and fine grain with the normal and floating habit, types different from the two parents.

SUMMARY

The habit of the deep-water rice designated ' floating habit ', though it develops properly only with deep-water conditions, can still be made out even under ordinary conditions. It grows much faster than rices of similar duration, particularly in the early stages, and at the later stages the whole plant leans over, the outer culms of the clump developing a tendency to sprawl on the water surface.

A cross between an ordinary rice and a rice with the floating habit has shown that the floating habit of the latter is controlled by duplicate recessive genes designated $\mathbf{ef}_1$ and $\mathbf{ef}_2$, the F_2 giving a 15 : 1 ratio of the normal to the floating habit.

The two parents differed in plant height, flowering duration and nature of tillering, and there was segregation for all these characters in the F_2. There was no genetic association between plant height and floating habit. With regard to flowering duration, however, lateness was a simple dominant to earliness, and the F_2 ratios would appear to indicate that the gene controlling duration in this case is linked with one of the genes controlling habit with about 30 per cent crossing-over.

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REFERENCES

Majid, S. (1936). *Rept. Deep Water Paddy Res. Sta.* (*Habiganj*), **1935-36**

Ramiah, K. (1930). *Mem. Dept. Agric. Ind.* (*Bot. Ser.*) **18, 211**

———— (1933). *Ind. J. Agric. Sci.* **3, 377**

Ramiah, K. and Dharmalingam, S. (1934). *Ind. J. Agric. Sci.* **4, 885**

INHERITANCE OF EARLINESS IN SURMA VALLEY RICES

BY

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(With six text-figures)

INTRODUCTION

THE groups to which rice belongs are generally termed summer, autumn-winter and spring rices, referring only to the period of harvest. According to this convention the Surma Valley rices are classified as follows :

Summer rices—(Early *aus*)—*dumai*, *murali* and *chengri*
Autumn rices—*Aus*
Winter rices—*Sali*, *asra* and *aman*
Spring rices—*Boro*

Flowering duration is, therefore, an important physiological character which should be studied in all its bearing. Summer and autumn rices are time-fixed and the winter rices are season-fixed [Mitra, 1937]. The time and period of flowering varies slightly from year to year. The length of the growing period varies a good deal with the climatic conditions of the locality as is also shown by Thadani [1928]. Inheritance of the flowering character in rice is therefore a complicated subject, and various results were obtained at different places and with different varieties.

Hoshino [1915] found in a cross between early and late maturing rice that the time of flowering in F_1 was intermediate but nearer that of the early parent. The F_2 generation equalled the combined range of the parents. The author suggested that three multiple genes would explain the results.

Ikeno [1918] reported that in crosses of early and late rices the F_1 was intermediate and segregation in F_2 was complex and apparently due to multiple factor.

Hector [1922] found that the F_2 progeny from a cross between an autumn and a winter rice segregated into two distinct groups with respect to date of flowering. These two flowering periods were the same as the flowering dates of the two parents with an interval of about three weeks during which time no blooming occurred. The ratio of early to late was approximately 1 : 3.

Nomura and Yamazaki [1925] found that the F_1 hybrids were a few days later in shooting than the late parent and in F_2 segregation was in the ratio of about 3 late to 1 early with transgressive segregation on both sides. For interpretation, the authors drew up a trigenic basis.

Bhide [1926] observed the dominance of lateness in a monogenic ratio in certain crosses while in other crosses, however, such dominance of lateness over earliness was not very evident.

While studying the crosses from various early and late types in rice, Jones [1928] observed that the F_1 plants might be earlier than the early parent, later than the late parent or nearer the early or late parent in time of flowering. The F_2 plants studied could not be placed with any degree of certainty in any of the simple or modified ratios. Transgressive inheritance occurred and there was a heaping up of plants in the intermediate position in F_2. He finally observed that two or more genetic factors are involved in the production of earliness in the rices studied.

In the course of the investigations on the inheritance of flowering duration and height, Ramiah [1933] observed the simple dominance of earliness in one cross and the converse of it in another. Six more crosses were also tried by him from four extracted types obtained from the above two crosses and the results were explained both on a multiple-factor hypothesis and on an inhibitory factor hypothesis, although the former gave wider scope to account for the wider variability arising from a greater number of pheno-type combinations.

Crescini [1930], while studying the behaviour of the character of earliness in the F_2 crosses of *T. vulgare,* observed in one cross the complete dominance of lateness in a clear 3 : 1 ratio. While the curve of variability of the F_2 of another cross was clearly bimodal with an incomplete dominance to the earlier parent, the curve for the F_2 of the third cross was also bi-modal but intermediate between the parents. The F_2 of the fourth cross was also intermediate and showed a marked transgression to the later parent.

Breeding by use of transgressive segregation, Roemer [1933] obtained in spring barleys certain segregates which eared as much as 10 days earlier than the early parent.

From the results of a study of earliness in some ***sathi*** crosses Sethi [1938] observed that the frequency distribution of flowering duration in F_2 was continuous and extended from the lower extreme of the early parent to well beyond the upper extreme of the late parent.

EXPERIMENTS AND DISCUSSION

Several crosses were tried between summer, autumn and winter rices and the results dealt with separately in each case.

1. Cross No. 1 (M 36-30 × As 15-5)

The early parent M 36-30 took about 71 days and the late parent As 15-5 about 112 days from sowing to flowering with a difference of about 41 days between the two parents. The F_1 plants were more or less intermediate with a mean duration of 80 days inclined much towards the early parent. The range of variation in F_2 was from 70 to 165 days with a mean duration of about 93 days. The early plants in F_2 just reach the flowering range of the early parent while the late plants go much beyond the range of the late parent, showing one-sided transgressive segregation. Fig. 1 shows the actual segregation of the F_2 progenies with a curve extending on one side and probably representing a multiple-factor hypothesis.

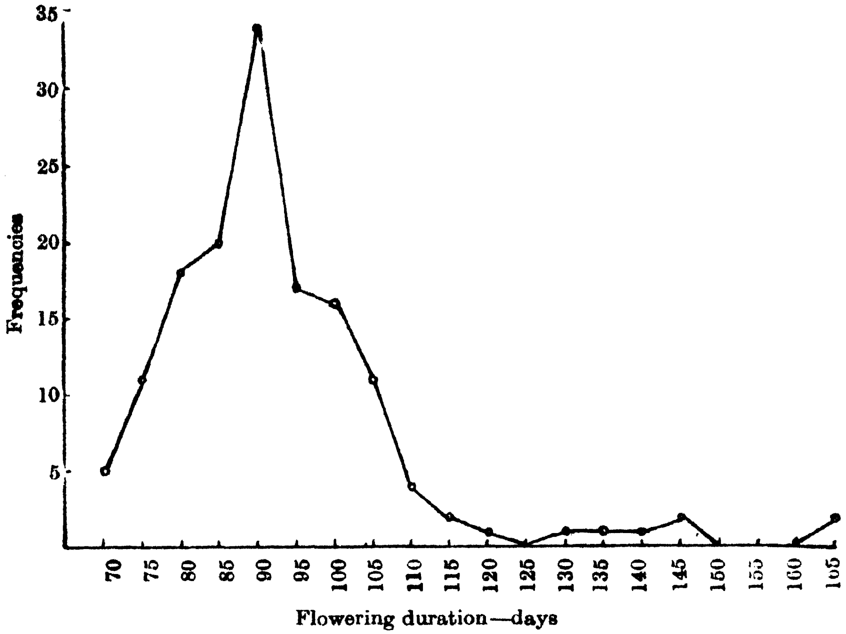

FIG. 1. Cross No. 1—F_2 generation

2. Cross No. 777 (D 138-6 × As 3)

One of the parents D 138-6 belongs to the earliest group, while the other parent As 3 is about 3 weeks later than the former. The flowering durations of the parent plants and the F_1 and F_2 plants are given below :—

	Range of variation in flowering (days)	Mean duration in flowering (days)
D 138-6	67—71	69
As 3	88—92	89
F_1	72—77	75
F_2	72—95	80

The above figures show that the F_1 plant is intermediate inclining towards the early parent. The F_2 plants segregate with a long range of variation. The early plants in F_2 just reach the flowering range of the early parent and do not overlap, while the late plants go slightly beyond the range of the late parent. Fig. 2 shows a normal curve indicating a multiple-factor hypothesis.

In F_3 some of the early and late plants bred true, while some segregated again into early and late.

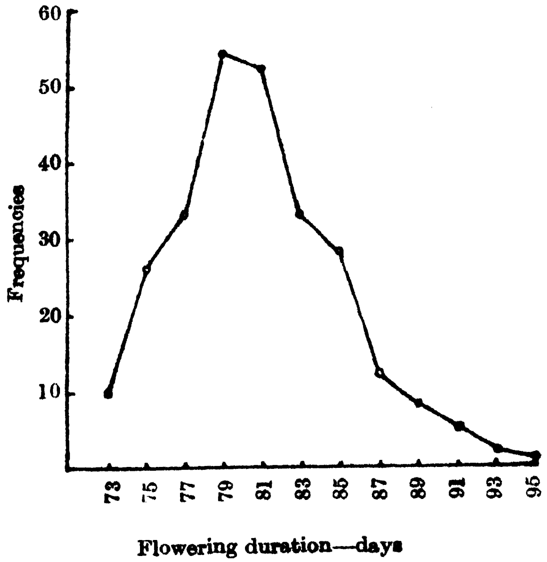

FIG. 2. Cross No. 777—F_2 generation

3. Cross No. 869 (As 3 × As 10)

The flowering durations of the parents and the F_1 and F_2 plants are shown below :—

	Range of variation in flowering (days)	Mean duration in flowering (days)
As 10	79—85	82
As 3	89—92	90
F_1	79—89	83
F_2	81—119	90

The above figures show that the F_1 plants are almost as early as the early parent. The F_2 plants have a wide range of variation just beginning with the early parent but going far beyond the late parent, i.e. the transgressive segregation is definitely one sided. Fig. 3 shows the segregation in F_2 with about a normal curve extending on one side and pointing to a multiple-factor hypothesis. In F_3 only a few of the early and late plants bred true while the majority segregated.

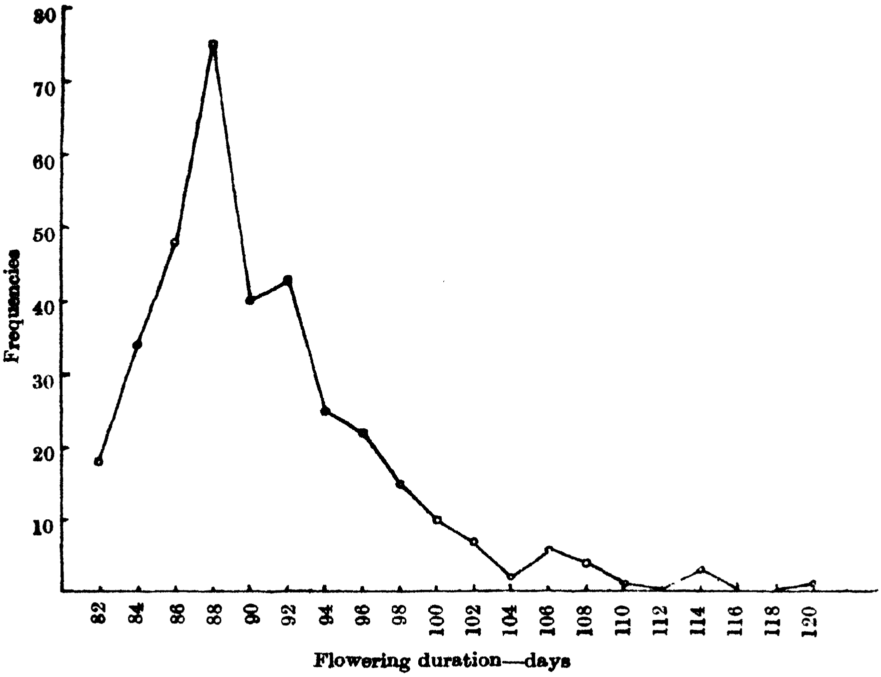

FIG. 3. Cross No. 869—F_2 generation

4. Cross No. 363 (M 36-30 × Ar 1)

This is a cross between a late summer and a winter paddy. The flowering durations of the parents and the F_1 and F_2 plants are shown below :—

	Range of variation in flowering (days)	Mean duration in flowering (days)
M 36—30	78—82	80
Ar 1	129—131	130
F_1	103—107	105
F_2	68—158	107

The above figures show that the F_1 is definitely intermediate, while F_2 has a wide range of variation beginning earlier than the early parent and finishing later than the late parent, i.e. unlike the previous crosses there is transgressive segregation on both sides. This may be explained on a duplicate factor hypothesis as done by Ramiah [1933].

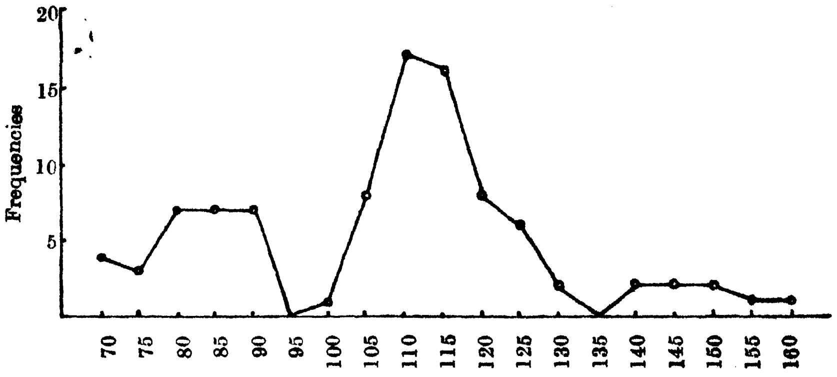

FIG. 4. Cross No. 363—F_2 generation

Fig. 4 shows graphically the segregation in F_2 with a bi-modal curve. There is a minimum frequency point at 95 days and the totals on either side of this give a clear ratio of 4 early : 12 late as shown below :—

Cross No. 363	Early	Late	Total
Observed	28	66	94
Calculated (4 : 12)	23·5	70·5	94

$\chi^2 = 1{\cdot}149$; $P = 0{\cdot}28$. The fit is fairly good.

5. Cross No. 546 (D 138-6 × Ar 1)

This is a cross between an early summer paddy and a winter paddy (the same as in the previous cross). The flowering durations of the parents and the F_1 and F_2 plants are shown below :—

	Range of variation in flowering (days)	Mean duration in flowering (days)
D 138—6	67—71	69
Ar 1	132—136	134
F_1	105—106	106
F_2	65—150	103

The above figures show that F_1 is definitely intermediate, while F_2 has a wide range of variation starting almost with early parent but finishing later than the late parent, i.e. the transgressive segregation here is rather one-sided. This may be explained on a triplicate-factor hypothesis supposing that the factor **E** makes the plant early and **L** makes the plant very late while **I**, an inhibitory factor, inhibits **L** and makes the plant somewhat earlier than the very late plant but later than the early plant. **E** is dominant over **L**. The genetic constitution of the parents and the F_1 and the factorial analysis of the F_2 is given below :—

D 138—6	**EEiill**	Early
Ar 1	**eeIILL**	Late
F_1	**EeIiLl**	Early
F_2	**27 EIL**	,,
	9 EIl	,,
	9 EiL	,,
	9 eIL	Late
	3 eIl	,,
	3 eiL	Very late
	3 Eil	Early
	1 eil	Late

48 early : 16 late

Fig. 5 shows the segregation in F_2 with a bi-modal curve. The total frequencies on the two sides of the break give a ratio of 48 early to 16 late as shown below :—

Cross No. 546	Early	Late	Total
Observed	108	44	152
Calculated (48 : 16)	114	38	152

$\chi^2 = 1{\cdot}263$; $P = 0{\cdot}26$. The fit is fairly good.

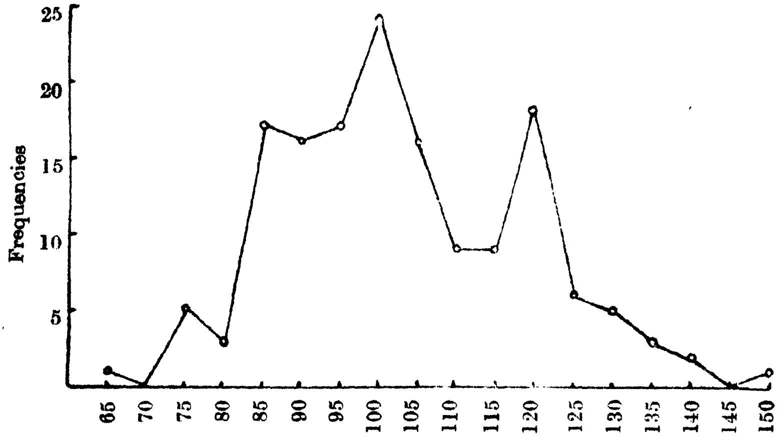

FIG. 5. Cross No. 546—F_2 generation

6. Cross No. 1520 (D 138-6 × S 22)

This is another cross between an early summer paddy and a winter paddy. The flowering durations of the parents and the F_1 and F_2 plants are given below :—

	Range of variation in flowering (days)	Mean duration in flowering (days)
D 138—6	69—78	72
S 22	163—166	165
F_1	128—134	133
F_2	68—183	117

The above figures show that the F_1 is more or less intermediate, inclined much towards the late parent. The F_2 plants have a wide range of variation just beginning with the early parent but going far beyond the late parent, i.e. the transgressive segregation is definitely one-sided. Fig. 6 shows the segregation in F_2 with a bi-modal distribution.

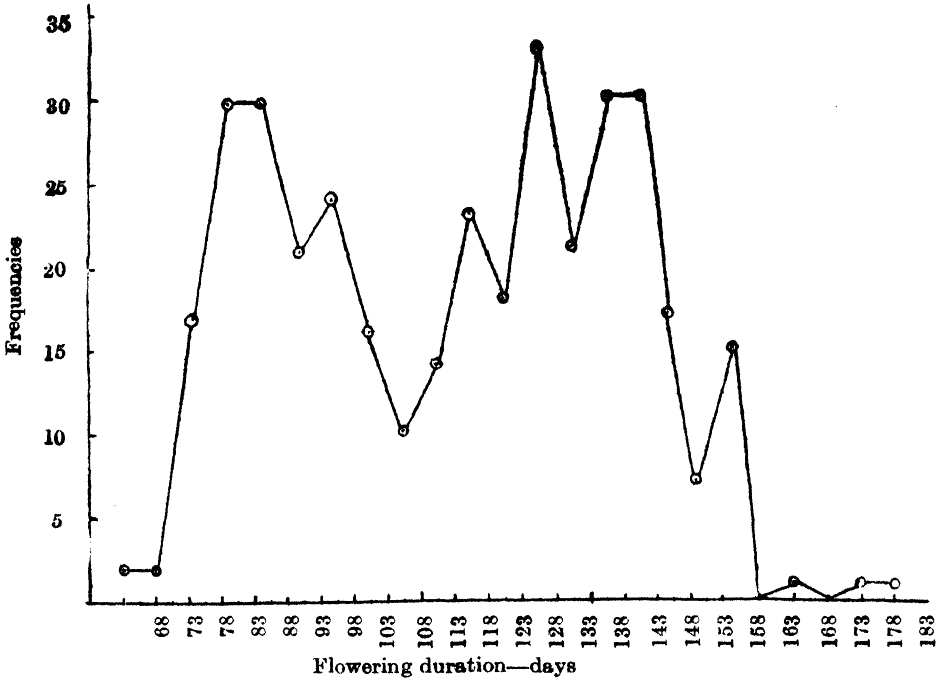

FIG. 6. Cross No. 1520—F_2 generation

Out of the 68 cultures of the cross No. 1520 studied in F_3 (Appendix) all the 25 early cultures bred true, while most of the intermediates segregated with a break as noticed in F_2. One intermediate culture (No. 103) was observed to be pure. Of the 11 late cultures five were found to be definitely pure, while slight fluctuations were noticed in four. Two of the lates, however, behaved like intermediates.

SUMMARY

Several crosses were made between some of the summer, autumn and. winter rices. The object of this study was to investigate the mode of inheritance of earliness of different classes of Surma Valley rice. The earliest type of paddy in our recommended list belongs to summer rice and is named D 138-6 The quest for a very early type with moderate yield had been going on, but unfortunately the earliest types hitherto tested possessed some defects which rendered it unwise to recommend them to the paddy growers. Hybridization was, therefore, resorted to for the production of high-yielding early types of paddy.

In a cross between a summer and an autumn rice there was a difference of about 41 days in flowering between the two parents. The F_1 plants were more or less intermediate, inclined much towards the early parent. The actual segregation of the F_2 progenies showed about a normal curve extending on one side and probably representing a multiple factor inheritance. The transgressive segregation was rather one-sided, i.e. the early plants were as early as the early parent, while some of the late plants were much later than the late parent. Two more crosses between the summer and autumn rices showed practically the same result.

In a cross between an autumn and a winter rice, the F_1 was definitely intermediate and the F_2 had a wide range of variations with transgressive segregation on both sides. Graphically, the F_2 population segregated with a bi-modal curve showing clearly a ratio of 3 late : 1 early.

In two other crosses between the summer and the winter rices, the F_1 was intermediate and in F_2 the transgression was again one sided, i.e. towards the lateness only.

Study of F_3 generation further showed the improbability of getting types earlier than the earliest parent. It is, therefore, not possible to obtain types earlier than the earliest parents as revealed from this study.

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REFERENCES

Bhide, R. K. (1926). *Poona Agric. Coll. Mag.* **18**, 76-85
Crescini, F. (1930). *Riv. Biol.* **12**, 193-206
Hector, G. P. (1922). [After Evans, G. : *Bengal Dept. Agric. Rept.* 1921-22]
Hoshino, Y. (1915). *J. Coll. Agric. Tohoku Imp. Univ.* **6**, 229-88
Ikeno, S. (1918). *Bot. Abs.* **2**, 114-5
Jones, J. W. (1928). *J. Agric. Res.* **36**, No. 7
Mitra, S. K. ; Gupta, S. N. and Ganguli, P. M. (1924). *Agric. J. Ind.* **19**, 590-9
Nomura, M. and Yamazaki, R. (1925). *Abs. Japan J. Bot.* **3** (18)
Ramiah, K. (1933). *Ind. J. Agric. Sci.* **3**, 377-410 ; 446-59
Roemer, T. (1933). *Plant Breeding Abs.* **3**, 605
Sethi, R. L. ; Sethi, B. L. and Mehta, T. R. (1938). *Ind. J. Agric. Sci.* **8**, 1-20
Thadani, K. I. and Durga Dutta, H. V. (1928). *Mem. Dept. Agric. Ind.* (*Bot. Ser.*) **15**, No. 6

APPENDIX

Cross No. 1520—frequency distribution of flowering duration in F_3 cultures

Culture No.	F_2 duration	F_3 mean	64	69	74	79	84	89	94	99	104	109	114	119	124	129	134	139	144	149	154	159	164	169	174	179	184	189	194	199	204	209	214	Total
Parents D 138—6	72	69	4	31	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	39
S 22	165	164	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	33	1	...	...	...	...	...	...	...	...	...	38
183	66	70	10	38	29	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	79
6	68	65	59	17	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	77
42	73	72	6	27	20	8	2	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	65
34	77	80	1	5	24	15	22	8	3	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	79
5	79	69	8	29	8	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	47
97	80	74	4	25	22	14	4	2	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	73
100	80	74	...	20	42	10	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	76
29	81	77	...	3	39	32	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
39	82	80	...	2	31	18	13	5	3	2	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	76
38	83	79	...	...	32	25	14	6	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
31	84	83	...	...	3	24	31	11	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	69
35	84	84	...	...	2	13	9	4	5	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	35
24	85	86	...	...	...	8	43	16	7	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	76
68	85	78	...	1	31	29	14	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	77
73	86	90	...	...	2	12	17	15	10	6	3	3	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	70
85	86	79	...	3	23	25	23	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	79
12	87	77	1	11	29	21	12	2	3	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
75	88	81	...	10	19	15	15	14	3	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
93	88	81	...	3	10	20	24	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	63
89	89	90	...	...	...	1	22	28	16	12	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
27	90	101	...	...	...	1	3	9	14	19	5	5	11	5	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	73

94	91	88	...	1	3	11	19	26	9	8	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	79
3	93	93	...	...	...	1	15	26	9	14	5	4	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	76
37	93	102	...	...	...	...	1	11	19	19	5	3	14	8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
1	96	82	...	...	4	35	32	4	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	78
8	97	147	...	1	3	...	...	...	...	...	1	...	...	...	1	6	8	1	2	10	22	12	8	2	...	1	2	...	...	...	...	...	...	80
17	99	96	1	8	9	14	4	1	4	9	4	5	4	6	3	1	3	...	...	2	...	...	1	...	...	...	...	...	...	...	...	...	...	79
82	99	104	...	2	10	13	8	1	...	1	2	2	7	5	9	6	6	3	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	77
78	104	126	...	...	...	...	...	...	1	1	...	4	2	12	14	14	9	5	...	2	...	1	...	...	...	...	...	...	...	...	...	...	...	65
72	105	115	...	2	7	16	7	1	...	1	...	2	1	7	2	...	10	2	7	1	4	...	2	1	2	3	1	...	...	...	...	...	...	79
80	106	100	3	11	16	5	3	1	1	1	2	3	6	6	4	3	2	4	2	2	1	2	1	...	...	...	...	...	...	...	...	...	...	79
77	108	106	...	1	9	7	8	5	1	...	...	1	...	4	3	...	4	3	2	1	...	1	...	1	1	2	...	...	...	...	...	...	...	54
86	108	113	...	...	17	7	1	1	1	4	1	2	4	7	3	2	5	3	1	4	5	1	3	3	...	...	...	...	...	...	...	...	...	75
90	110	112	...	...	...	5	10	8	1	6	1	2	2	11	2	1	15	9	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	75
10	111	109	...	...	1	4	3	11		3	6	4	12	18	10	2	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	79
47	111	115	...	...	3	3	5	2	1	1	...	2	7	22	8	5	4	6	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	70
98	116	124	...	...	...	...	1	3	...	4	1	...	4	12	11	5	19	6	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	68
14	120	127	...	...	1	...	9	2	2	...	...	...	...	...	1	...	1	2	4	3	3	1	...	...	...	...	3	2	...	...	...	...	...	34
32	120	121	...	...	...	1	4	4	1	1	...	...	...	5	16	4	3	4	8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	51
36	120	113	...	1	5	8	8	2	1	3	...	...	...	4	19	1	12	11	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	76
101	121	123	...	...	6	2	...	1	...	1	...	...	...	...	4	17	22	7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	60
61	122	117	...	...	...	2	8	6	3	3	1	...	2	3	24	14	5	5	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	79
66	127	119	...	...	...	3	2	5	2	...	1	...	...	...	...	4	15	4	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	38
79	127	121	...	...	2	8	8	3	...	3	2	2	2	3	4	6	7	6	4	4	3	2	2	2	1	1	...	...	...	...	...	...	...	75
74	129	133	...	...	2	1	...	...	...	...	...	...	3	8	3	3	8	20	14	3	1	...	...	...	...	...	...	...	...	...	...	...	...	66
102	129	130	...	...	...	...	...	...	...	...	...	...	...	...	30	22	9	7	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	73
78	130	119	...	...	5	4	6	3	1	1	1	...	...	3	3	2	6	9	3	4	5	2	...	...	...	...	...	...	...	...	...	...	...	58
69	133	132	...	...	...	...	2	...	...	1	1	2	4	...	...	1	4	13	6	2	1	...	...	...	...	1	...	...	...	...	...	...	...	38
88	133	127	...	...	...	4	4	8	1	...	...	...	...	...	...	1	24	25	13	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80
71	138	128	...	...	1	1	4	6	5	1	...	...	...	3	3	2	4	12	10	10	4	3	1	...	...	...	...	...	...	...	...	...	...	70
30	139	134	...	...	...	1	2	2	3	2	...	...	3	...	3	...	3	11	8	7	6	2	4	...	...	...	...	...	...	...	...	...	...	57

APPENDIX—*contd.*

Culture No.	F_3 duration	F_3 mean	64	69	74	79	84	89	94	99	104	109	114	119	124	129	134	139	144	149	154	159	164	169	174	179	184	189	194	199	204	209	214	Total
76	140	135	...	...	...	1	5	10	1	1	...	1	...	...	...	...	6	14	10	4	10	3	5	1	2	1	...	1	1	...	...	...	...	77
84	140	124	...	...	9	10	3	...	1	...	...	1	1	...	8	7	11	4	1	5	5	...	4	2	...	...	3	2	...	...	...	...	...	77
57	143	127	...	...	...	2	5	6	3	6	5	2	...	3	...	1	1	6	5	15	6	3	4	2	1	1	...	1	...	...	...	...	...	78
81	143	140	...	1	1	1	1	...	1	...	...	...	...	3	8	2	2	10	18	13	9	4	2	...	2	...	...	...	...	...	...	...	...	78
87	144	126	...	...	...	1	...	4	4	12	3	1	...	...	3	6	5	11	11	7	6	1	...	...	...	...	...	...	...	...	...	...	...	75
83	146	139	...	1	...	3	1	1	3	...	...	2	...	...	6	5	1	7	14	14	10	3	5	...	...	1	...	2	...	...	...	...	...	79
25	150	167	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	1	...	...	18	12	15	7	8	3	2	...	1	...	...	...	69
40	150	137	...	...	...	...	...	...	2	4	10	3	2	...	...	...	1	3	7	22	18	3	...	...	...	...	...	...	...	...	...	...	...	75
2	156	139	...	...	...	...	...	...	...	2	10	5	...	...	...	...	...	...	...	24	7	9	1	...	...	...	...	...	...	...	...	...	...	58
16	156	148	...	...	...	...	...	...	2	2	1	...	...	...	1	4	7	2	5	13	15	15	3	2	2	2	1	...	...	...	...	...	...	77
103	156	156	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	8	2	25	25	4	4	2	2	...	...	...	...	...	...	...	78
33	157	147	...	...	...	2	1	1	...	...	...	...	...	...	...	2	4	4	4	5	21	15	2	1	...	1	1	1	...	...	...	...	...	65
92	160	150	...	...	...	...	1	1	...	1	...	...	1	...	...	...	1	14	7	7	16	15	3	3	2	2	1	...	...	...	...	...	...	75
96	160	164	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	14	21	20	5	1	2	7	4	...	...	...	...	...	76
165	166	167	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	16	36	11	3	5	5	...	2	...	...	...	...	78
158	179	182	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	8	19	24	14	6	...	...	...	...	79
340	181	191	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	11	31	23		3	...	2	76

ELEVEN YEARS' RESULTS OF CONTINUOUS MANURING OF PADDY AT MANDALAY

BY

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(Received for publication on 10 May 1940)

(With one text-figure)

I. INTRODUCTION

THE present study is an examination of eleven years' data from the paddy permanent manurial experiment conducted at the Mandalay Agricultural College Farm since 1927. The experiment consists of 74 plots, each of 0·1 acre, arranged in two rows of 37 plots. The plots were originally laid down in 1924-25 but as no record had been kept of previous treatments two crops without manures were taken in the years 1924-25 and 1925-26 in order to reduce plot differences.

The object of the experiment is to study the influence of various manures on the soil of the Mandalay Farm and in particular the manner in which the soil fertility is affected by repeated applications of chemical and organic fertilizers.

II. MANURIAL TREATMENTS

The manurial dressings were as follows :

(*a*) Lime, 5 cwt CaO per acre, once in four years ; second application in 1930-31 and third application in 1934-35
(*b*) Sodium nitrate, 40 lb. N_2 per acre
(*c*) Ammonium sulphate, 40 lb. N_2 per acre
(*d*) Superphosphate, 40 lb. P_2O_5 per acre
(*e*) Bone-meal, 40 lb. P_2O_5 per acre
(*f*) Potassium sulphate, 40 lb. K_2O per acre
(*g*) Ammonium sulphate, 40 lb. N_2 per acre *plus* superphosphate, 40 lb. P_2O_5 per acre
(*h*) Ammonium sulphate, 40 lb. N_2 per acre *plus* superphosphate, 40 lb. P_2O_5 per acre *plus* potassium sulphate, 40 lb. K_2O per acre
(*i*) Farmyard manure, 40 lb. N_2 per acre

The manures were applied shortly before transplanting, and the variety of paddy grown is Ngasein C 2104. The plots are irrigated, the average rainfall being only about 33 in. The soil is a heavy black clay of the carbonate solontschak type having a *p*H of about 8·05.

III. LAYOUT AND METHOD OF ANALYSIS

The experiment is laid out in two series of two blocks each with 37 plots in each series. Each plot is 165 ft. × 26 ft. 5 in. or 1/10th acre approximately. Of the 74 plots, 38 are used as controls (without manures) and the nine manurial treatments are replicated four times. The actual layout is shown in the diagram, and it will be seen that treated and untreated plots alternate.

Size of plot = 165 ft. × 26 ft. 5 in. = 1/10 acre

Bund between plots = 4 ft.

N

	Planted not weighed		Planted not weighed	
‘C’ Block	38. Control	IRRIGATION CHANNEL	1. Control	‘A’ Block
	39. Lime		2. Lime	
	40. Control		3. Control	
	41. Sodium nitrate		4. Sodium nitrate	
	42. Control		5. Control	
	43. Ammonium sulphate		6. Ammonium sulphate	
	44. Control		7. Control	
	45. Superphosphate		8. Superphosphate	
	46. Control		9. Control	
	47. Bone-meal		10. Bone-meal	
	48. Control		11. Control	
	49. Potassium sulphate		12. Potassium sulphate	
	50. Control		13. Control	
	51. $(NH_4)_2SO_4$ + super		14. $(NH_4)_2SO_4$+super	
	52. Control		15. Control	
	53. $(NH_4)_2SO_4$ + super + K_2SO_4		16. $(NH_4)_2SO_4$ + super + K_2SO_4	
	54. Control		17. Control	
	55. Farmyard manure		18. Farmyard manure	
‘D’ Block	56. Control		19. Control	‘B’ Block
	57. Lime		20. Lime	
	58. Control		21. Control	
	59. Sodium nitrate		22. Sodium nitrate	
	60. Control		23. Control	
	61. Ammonium sulphate		24. Ammonium sulphate	
	62. Control		25. Control	
	63. Superphosphate		26. Superphosphate	
	64. Control		27. Control	
	65. Bone-meal		28. Bone-meal	
	66. Control		29. Control	
	67. Potassium sulphate		30. Potassium sulphate	
	68. Control		31. Control	
	69. $(NH_4)_2SO_4$ + super		32. $(NH_4)_2SO_4$ + super	
	70. Control		33. Control	
	71. $(NH_4)_2SO_4$ + super + K_2SO_4		34. $(NH_4)_2SO_4$ + super + K_2SO_4	
	72. Control		35. Control	
	73. Farmyard manure		36. Farmyard manure	
	74. Control		37. Control	
	Planted not weighed		Planted not weighed	

The layout is unsatisfactory because of want of randomization and of the multiplicity of untreated plots. These may lead to a biased estimate of error. Fisher's [1934] method of analysis has, however, been used on the assumption that the condition of randomness is approximately satisfied although the treatments are not properly randomized.

IV. RELATIVE EFFICIENCY OF VARIOUS MANURIAL TREATMENTS

The yields of all the plots of the four replications for 11 years, excepting those of plot Nos. 37 and 74 which are the end odd plots in each series, are analysed together. The variance has been split into : (1) influence of blocks, (2) effect of various manurial dressings, (3) effect of annual fluctuations, (4) differential response of the treatments with respect to season, and (5) steady deterioration of the soil. From the yields of only 72 plots for each year there were 791 degrees of freedom available. The details of the analysis are given in Table I.

TABLE I

Analysis of variance of yields in kg.

	Degrees of Freedom	Sum of squares	Mean square	Observed value of F
Blocks	3	9,935·3758	3,311·7919	49·6152
Treatments	9	107,740·8738	11,971·2082	179·3453
Regression	(1)	(69·0929)	69·0929	1·0352
Deviations from regression .	(9)	(62,846·3213)	6,982·9246	104·6139
Years	10	62,915·4142	6,291·5414	94·2560
Interaction between treatments and years	90	10,127·4193	112·5268	1·6858
Residual error	679	45,322·8978	66·7495	
Total . .	791	236,041·9809		

The following conclusions can be drawn :

(1) The treatment differences are significant (P less than 0·01).

(2) The seasonal differences are significant (P less than 0·01).

(3) Further analysis indicates that the deterioration as shown by the linear function is insignificant (P greater than 0·05).

(4) Block differences are highly significant (P less than 0·01).

(5) The relative efficiencies of the manurial treatments show significant variation from year to year, i.e. there is definite differential response of the treatments to years (P less than 0·01).

Soil variation

As the experiment was laid out in four replications in two adjacent parallel rows, partition of the block variance into three portions is possible. It is given in Table II.

TABLE II

Analysis of block variance (yields in kg.)

Due to	Degrees of freedom	Sum of squares	Mean square
Series	1	4,683·7791	4,683·7791
Columns	1	5,230·2584	5,230·2584
Residual block variance . . .	1	21·3383	21·3383
Total for blocks	(3)	(9,935·3758)	3,311·7917
Error	679	45,322·8978	66·7495

The above analysis shows that the high value of block variance is due to the presence of highly significant differences between one series and the other and between one column and the other.

TABLE III

Mean yields of blocks in lb.

	Block A	Block B	Block C	Block D	Mean	S. E. diff.	C. D. at 5 per cent point
Mean yields in lb.	1,576·26	1,455·72	1,676·23	1,570·18	1,569·60	18·113	35·592

The mean difference in yield of the two series is 4·8637±0·5807 and the mean difference between the two columns is 5·1395±0·5807. From this it follows that the fertility slope runs from east to west, and from north to south.

V. ANNUAL FLUCTUATIONS

The analysis of variance definitely indicates that the mean yields vary considerably from year to year. The annual mean yields are given in Table IV and graphically in Fig. 1.

TABLE IV

Mean yields of Ngasein in lb. per acre

Year	Mean yield	General mean	S. E. diff.	C. D. at $P=0{\cdot}05$
1927	1,523·29	1,569·60	30·0203	59·0000
1928	1,633·76			
1929	1,500·44			
1930	1,242·32			
1931	1,586·76			
1932	1,810·71			
1933	1,687·76			
1934	1,858·88			
1935	1,685·95			
1936	1,201·13			
1937	1,534·65			

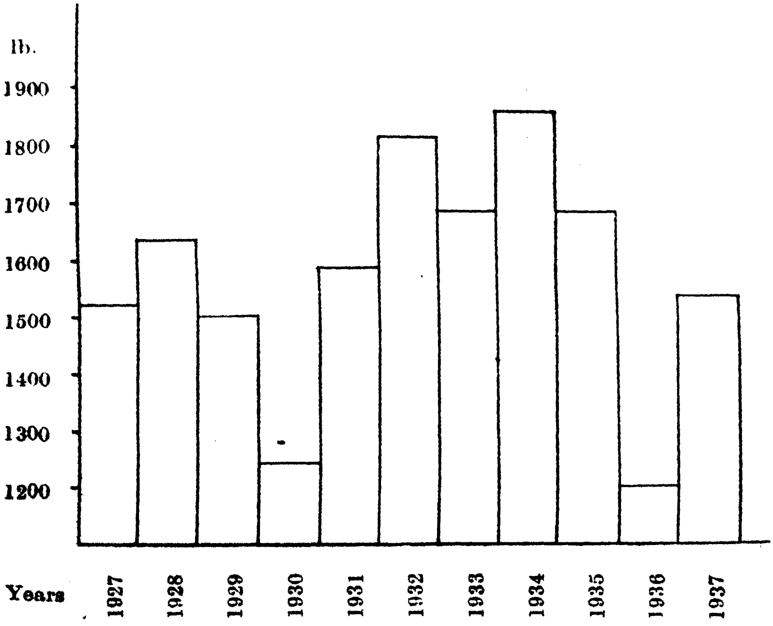

FIG. 1. Mean yields of Ngasein in lb. per acre

Thus the yield varied from 1,858·88 lb. per acre in 1934 to 1,201·13 lb. in 1936. These differences must be attributed to various factors, such as rainfall (especially rainfall during the flowering period), humidity, temperature, pests, etc. together with other variations such as those caused by changes in the method of cultivation, steady changes and other types of fluctuation in the soil due to continuous cropping.

Variance due to steady deterioration, which forms part of the annual fluctuation, is insignificant, while the variance due to deviation from the linear regression is significant. This shows the presence of various types of non-linear variation other than those which cause steady linear deterioration.

The mean yields of the treatments are given in Table V.

TABLE V

Mean yields in lb. per acre of 10 treatments

Order of merit	Treatments	Mean* yields in lb. per acre	S. E. diff. and C. D. ($P=0\cdot05$) for comparing one treatment against another	S. E. diff. and C. D. ($P=0\cdot05$) for comparing treated against control
9	No manure (Control) .	1,402·08	S.E. diff. =38·411 C. D. =75·478	S. E. diff. =28·620 C. D. =56·238
7	Lime	1,449·29		
6	Sodium nitrate . .	1,473·64		
5	Ammonium sulphate .	1,779·97		
4	Superphosphate . .	1,936·09		
8	Bone-meal . . .	1,446·43		
10	Potassium sulphate .	1,401·06		
1	Ammonium sulphate + superphosphate	2,076·21		
2	Ammonium sulphate+ superphosphate+potassium sulphate	2,054·49		
3	Farmyard manure. .	2,016·91		

* The mean yield for the control is calculated from the total of 396 plot yields and for other treatments from totals of 44 plot yields each.

All the manures except lime, bone-meal and potassium sulphate show significant increases over the untreated plots. Of the effective manures sodium nitrate is just significantly better than no manure, while ammonium sulphate alone is very much better than sodium nitrate but inferior to all phosphatic manures and to farmyard manure. Superphosphate alone, though inferior in yield to the two manurial combinations, has given a greater increase in yield from year to year as shown by the analysis given later.

The three manures applied on a nitrogen-content basis differ from one another significantly. From the mean yields it seems that nitrogen in organic form is the best while nitrogen as ammonia comes second.

VI. EFFECT OF THE UNCONSUMED RESIDUE OF THE FERTILIZERS ON THE YIELD OF THE SUCCEEDING CROP

Proceeding now to a consideration of the variation in yield of treated plots from year to year, of the several causes of annual fluctuation in yield the two most important considered here are pure seasonal fluctuation and the cumulative effect of the manures applied in previous seasons.

Fisher [1921] and Kalamkar and Singh [1935] recognize three types of variations : (1) Annual fluctuations, (2) Fluctuation due to soil deterioration, (3) Slow changes other than a steady deterioration. In order to assess the effect of soil deterioration and of slow changes, it is necessary to have data for a period of 30 to 40 years for the same plot. Such data are not available in Burma at present and will not be available for many years. Meanwhile it is desirable to examine whether any large trends follow or are likely to follow the continued use of certain artificials.

The present data relate to an experiment which has lasted only for eleven years, which is too short a time for an analysis of all three types of variation. Therefore, only the variation caused by the cumulative effects of the manurial treatments is considered, this being the point on which information is urgently desired. If it is assumed that season affects the yield of treated and untreated plots alike, then the seasonal effect on the yields of the manured plots can be treated as a partial regression on the yields of the untreated. On this assumption the following multiple regression has been fitted to the yield data :—

$$y-\bar{y}=b_1\ (x_1-x_1)+b_2\ (x_2-\bar{x}_2)$$

where y is the yield of the manured plot, x_1 the progressive number of doses of manure and x_2 the yield of the corresponding control.

The analysis is given in Table VI. Lime is omitted as it was only applied once in four years.

In all cases except superphosphate and farmyard manure the standard errors of the regression coefficients of the cumulative doses on the yield are proportionately so high that significance is not attained. Superphosphate in combination with ammonium sulphate, with or without potassium sulphate, fails to give a significant regression of cumulative dose effect. The marked negative trend of ammonium sulphate alone, though not significant, may be surmised to have reduced the positive superphosphate trend so as to cause it to fail in significance.

It therefore seems likely that the continued use of ammonium sulphate alone may lead to a decline in yield and that the continued use of superphosphate will tend to build up fertility. So far as these studies go, on a very limited scale, there would therefore appear to be no danger in repeated applications of the newer types of ammonio-phosphatic fertilizers such as are generally recommended for paddy in Burma, but the question remains as to whether the inclusion of nitrogen is worth while and whether in the long run phosphate alone may not raise the fertility level more and ultimately prove equally or more profitable.

TABLE VI

Analysis of variance (11 years)

(Calculated on yield in kg.)

Manure	Due to	Degrees of freedom	Mean square	Regression coefficients	
				Cumulative dose effect b_1	On yields of control b_2
Sodium nitrate	Blocks	3	452·3589		
	Regression functions b_1	1	107·4980		
	Regression functions b_2	1	4,287·2106	—1·1439±1·482	+0·9742±0·1166
	Deviations from regression	8	58·3698		
	Annual fluctuation	(10)	486·1667	$R=0·9508$	
	Error	30	56·9108		
Ammonium sulphate	Blocks	3	438·9180		
	Regression functions b_1	1	68·4444		
	Regression functions b_2	1	3,949·6400	—2·6302±1·553	+0·8907±0·1149
	Deviations from regression	8	65·0270		
	Annual fluctuation	(10)	453·8301	$R=0·9410$	
	Error	30	37·9457		
Superphosphate	Blocks	3	128·3240		
	Regression functions b_1	1	3,838·4134		
	Regression functions b_2	1	3,100·9268	+12·3184±1·8858	+0·9685±0·1633
	Deviations from regression	8	97·0168		
	Annual fluctuation	(10)	771·5475	$R=0·9455$	
	Error	30	34·8765		
Bone-meal	Blocks	3	39·7760		
	Regression functions b_1	1	177·6997		
	Regression functions b_2	1	3,332·4826	+3·1185±2·445	+0·8612±0·1887
	Deviations from regression	8	162·9242		
	Annual fluctuation	(10)	483·3576	$R=0·8522$	
	Error	30	59·3836		
Potassium sulphate	Blocks	3	257·0431		
	Regression functions b_1	1	123·5990		
	Regression functions b_2	1	2,140·0307	—2·0989±1·264	+0·7516±0·1080
	Deviations from regression	8	43·9908		
	Annual fluctuation	(10)	261·5553	$R=0·9303$	
	Error	30	43·9482		

TABLE VI—*contd.*

Manure	Due to	Degrees of freedom	Mean square	Regression coefficients	
				Cumulative dose effect b_1	On yields of control b_2
Ammonium sulphate + superphosphate	Blocks	3	119·6447		
	Regression functions b_1	1	313·3749		
	Regression functions b_2	1	1,314·1318	+3·7390±4·119	+0·5765±0·3500
	Deviations from regression	8	462·1837		
	Annual fluctuation .	(10)	532·4976	R=0·5528	
	Error	30	43·1587	(Not significant)	
Ammonium sulphate + superphosphate + potassium sulphate	Blocks	3	232·7198		
	Regression functions b_1	1	332·0372		
	Regression functions b_2	1	1,829·1745	+4·0357±3·580	+0·6547±0·2806
	Deviations from regression	8	347·0523		
	Annual fluctuation .	(10)	493·7630	R=0·6616	
	Error	30	45·4607	(Passes the 5 per cent point)	
Farmyard manure	Blocks	3	209·3569		
	Regression functions b_1	1	3,466·7077		
	Regression functions b_2	1	2,637·5091	+12·0847±4·030	+0·9437±0·3533
	Deviations from regression	8	436·1186		
	Annual fluctuation .	(10)	959·3642	R=0·7977	
	Error	30	87·6373		

Of the two sets of regression coefficients the more interesting one—the cumulative dose effect on the yield—shows that in the cases of superphosphate and farmyard manure, if the yields of the controls were constant, an addition of one dose would cause an increase of about 30 kg. or 66 lb. of paddy per acre per annum.

The multiple correlation coefficients are significant in all cases except for ammonium sulphate *plus* superphosphate. The significance in most cases is due to the close relation in behaviour towards the weather effects by the treated and untreated.

Analysis also shows clearly (Table VI) that the two factors together account for a significant fraction of the total variance due to annual causes. For superphosphate the total sum of squares due to the regression functions is 6,939·3402, which is proportionately contributed by the two influencing factors, their sums of squares being 3,838·4134 and 3,100·9268. Farmyard manure behaves in a similar way, the total sum of squares, 6,104·2168, being made up of 3,466·7077 and 2,637·5091, which are respectively the sum of squares of the regression function of the cumulative dose and of the yield of the corresponding controls. In both cases it is interesting to note that the cumulative dose effect takes the larger share of the contribution towards the total sum of squares.

In all other cases the contribution towards the total sum of squares by the cumulative dose effect is disproportionately low in comparison with the share contributed by the regression function of the yield of the corresponding control. Especially is this so in the case of the two nitrogenous manures, ammonium sulphate and sodium nitrate, where the sum of squares due to cumulative dose effects are only 68·444 in 4,018·0844 and 107·4980 in 4,394·9086 respectively.

VII. SUMMARY

1. The yields of paddy (Ngasein C2104) of the permanent manurial experiment at Mandalay from 1927 to 1937 have been analysed.
2. The effects of cumulative doses of various manures in relation to the corresponding control have been studied.
3. Multiple regressions have been fitted to the annual mean yields.
4. It has been observed that the relative efficiency of manurial treatments shows significant variation from year to year.
5. The presence of non-linear variations other than those which cause steady linear deterioration is apparent.
6. Of the three nitrogenous manures, organic manure is the best with respect to the yield of paddy grain, while ammonium sulphate is much superior to sodium nitrate.
7. Bone-meal shows no significant increase. This was to be expected in a soil of about *p*H 8·0.
8. It has been observed also that of all the artificials only superphosphate applied alone at the rate of 40 lb. P_2O_5 per acre has shown a significant upward trend.
9. Farmyard manure shows a similar effect to superphosphate, though not so highly significant.
10. Sodium nitrate and ammonium sulphate show negative trends. The former's trend is quite insignificant but that of the latter only just fails to reach significance.
11. The combined manures, ammonium sulphate *plus* superphosphate and ammonium sulphate *plus* superphosphate *plus* potash show positive trends, but they are quite insignificant. It is suggested that the negative effect of ammonium sulphate has largely counteracted the significantly positive effect of superphosphate.

This work has been carried out under the supervision of Mr D. Rhind, I.A.S., Economic Botanist, Burma, to whom the author is greatly indebted for his suggestions and assistance in writing this paper, and also to the Professor of Agriculture for making the data available.

REFERENCES

Annual Reports of the Dept. of Agric., Burma, 1924 to 1938

Fisher, R. A. (1921). *J. Agric. Sci.* **11,** 107

———— (1924). *Phil. Trans.* **B 213,** 89

———— (1934). *Statistical methods for research workers* : Oliver and Boyd

Kalamkar, R. J. and Singh, Sripal (1935). *Ind. J. Agric. Sci.* **5,** 346

FURTHER OBSERVATIONS ON STERILITY IN COTTON

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(With three text-figures)

INTRODUCTION

HUTCHINSON and Gadkari [1935] described two sterile mutants in 'Million Dollar' (*G. arboreum* var. *neglectum* forma *burmanica* H. & G.), a strain of Asiatic cottons. It was shown there that the sterility of one of the plants—rogue B—was due to a single recessive gene to which Hutchinson and Silow [1939] have given the symbol **stp**. Fertility was fully dominant. It was further pointed out that the sterility though not quite complete was equal on both male and female sides. The percentage of shrivelled pollen grains varied among different sterile plants but it was always more than 70, whereas fertile plants had never more than 10 per cent bad pollen.

CYTOLOGY

Young anthers of both sterile and fertile plants were fixed in Carnoy's fluid and examined in acetocarmine. The fertile plants showed the normal tetrad formation, whereas in sterile plants usually six to eight unequal cells are formed from the division of the pollen-mother cell, rarely four as in a normal plant. This suggested some abnormality in the meiosis under genic control.

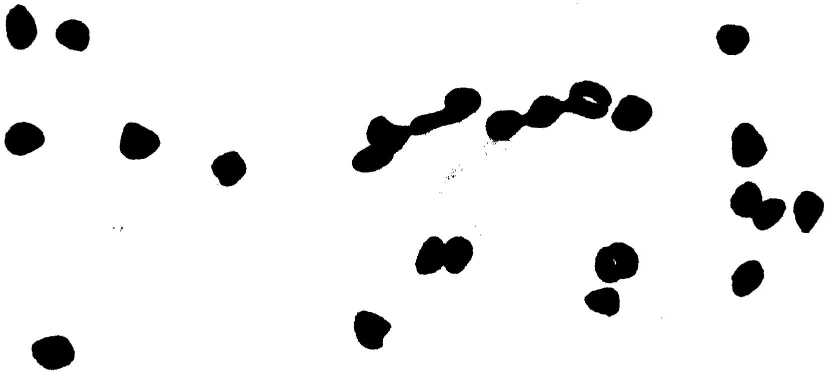

FIG. 1. Diakinesis stage of the pollen-mether cell of a sterile plant (× 3033)

A number of spore mother cells from different sterile plants were examined at diakinesis. All of them were characterized by a number of univalents, a few bivalents and some multivalents. One such case is represented in Fig. 1. This compared with the normal pairing, and formation of 13 bivalents in the normal fertile plant (Fig. 3) clearly suggests the absence of normal pairing, asynapsis, as the cause of sterility. In the anaphase stage of the sterile plant (a case represented in Fig. 2) one can see considerable fragmentation of the chromosomes and bridge formations.

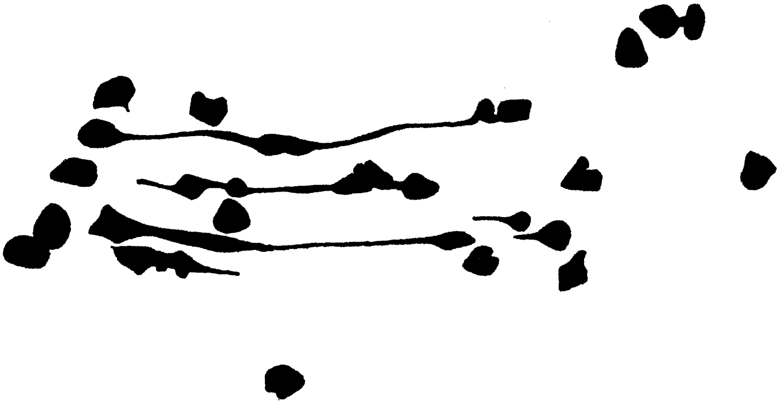

FIG. 2. Anaphase stage of a sterile plant (× 3033)

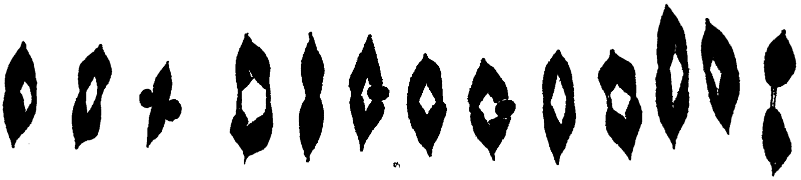

FIG. 3. Normal metaphase pairing—from a normal fertile plant—showing regular pairing and 13 bivalents (× 3033)

Similar asynaptic mutants have been reported by different workers in other plants, viz. *Zea* [Beadle, 1930], *Nicotiana* [Clausen, 1931], *Avena* [Huskins and Hearne, 1933], *Datura* [Bergner *et al.*, 1934], *Crepis* [Richardson, 1935], *Oryza* [Ramanujam and Parthasarthy, 1936], and *Pisum* [Koller, 1938]. In most of these cases definite reasons for the failure of the metaphase pairing have been suggested. The exact behaviour of the chromosomes leading to asynapsis in the present case is under investigation and is outside the scope of this note.

LINKAGE RELATIONS

Crosses detailed below were effected to study the linkage relations of this gene with other known ones in cotton. Owing to the failure of seed production in the homozygous steriles, both on selfing and on crossing, the heterozygous fertiles were utilized for the purpose. Due to complete dominance of fertility, however, it was impossible to distinguish between homozygous and heterozygous fertiles except by progeny tests. Crosses were therefore made with several fertile selections from a segregating progeny. All the crosses that happened to be made with the homozygous fertiles were discarded, attention being confined to series where the heterozygous fertile was the parent.

The heterozygous fertiles were homozygous for yellow corolla (**Ya**) and anthocyanin gene $\mathbf{R}_2^{As}$. These were crossed to N6, a type with white corolla (**yy**) and ghost spot $\mathbf{R}_2^{Os}$. The results are discussed below.

Heterozygous fertile ×N6

N6 was successfully hybridized with two heterozygous fertile plants, viz 384 and 494. All the F_1 plants were perfectly fertile and had yellow corolla and petal spot. The F_2 showed, as expected, two types of families with regard to sterility distribution. Some bred true for fertility while others segregated into fertiles and steriles. The distribution of the families in F_2 was as follows :-

	Families giving all fertiles	Families segregating into fertiles and steriles	Total
N6×384	6	4	10
N6×494	2	2	4
Total (observed)	8	6	14
Total (expected)	7	7	14

$\chi^2 = 0 \cdot 28$, $n = 1$, $P = 0 \cdot 70\text{-}0 \cdot 50$: Good fit

The total fertiles and steriles appearing in F_2 families segregating for sterility were as expected.

	Fertiles	Steriles	Total
N6×384	118	40	158
N6×494	33	15	48
Total (observed)	151	55	206
Total (expected)	153·5	51·5	206

$\chi^2 = 0 \cdot 29$, $n = 1$, $P = 0 \cdot 70\text{-}0 \cdot 50$; Good fit

The pooled distribution for corolla colour and anthocyanin genes in families segregating for sterility was as follows :—

	X	**x**	Total	χ^2	*P*
Anthocyanin . . .	141	39	180	1·06	0·50-0·30
Corolla colour . . .	142	46	188	0·03	0·90-0·80

These figures indicate the usual monogenic behaviour of the genes and as such their segregation in F_2 of double heterozygotes can be utilized for linkage estimation.

(i) Sterility and anthocyanin

The two-factor distribution for these two characters is given below :—

	Fertiles		Steriles			χ^2		
Family	$\mathbf{R_s^{As}}$	$\mathbf{R_s^{os}}$	$\mathbf{R_s^{As}}$	$\mathbf{R_s^{os}}$	Total	$\mathbf{R_s^{As}}$—$\mathbf{R_s^{os}}$	**Stp—stp**	(Linkage)
307 . .	9	3	2	3	17	0·96	0·18	2·89
308 . .	39	11	8	3	61	0·14	1·58	0·15
312 . .	28	8	10	3	49	0·17	0·06	0·00
313 . .	5	..	1	..	6	2·00	0·22	0·07
319 . .	24	6	9	2	41	0·66	0·07	0·02
323 . .	5	..	1	..	6	2·00	0·22	0·07
Total .	110	28	31	11	180	1·06	0·27	0·63

Thus the data indicate free assortment. These results were confirmed during the following year when selfed seed from heterozygous fertiles was used to grow an F_3. The double heterozygotes (11 families) gave the following distribution in F_3.

Fertiles		Steriles			χ^2		
$\mathbf{R_s^{As}}$	$\mathbf{R_s^{os}}$	$\mathbf{R_s^{As}}$	$\mathbf{R_s^{os}}$	Total	$\mathbf{R_s^{As}}$—$\mathbf{R_s^{os}}$	**Stp—stp**	(Linkage)
68	31	25	8	132	1·45	0·00	0·66

Thus there is no linkage between the sterility gene and anthocyanin.

(ii) Sterility and corolla colour

The crosses and families mentioned above segregated for corolla colour as well. The F_2 segregation was as follows :—

	Fertiles		Steriles			χ^2		
Family	Yellow	White	Yellow	White	Total	**Ya—ya**	**Stp—stp**	(Linkage)
307	8	3	2	3	16	1·33	0·33	2·78
308	45	5	7	4	61	3·42	1·58	3·62
312	23	12	12	2	49	0·33	0·33	2·17
313	4	1	..	1	6	0·22	0·22	1·85
319	23	7	11	..	41	1·37	0·07	2·20
323	2	3	..	1	6	5·55	0·22	0·07
Total .	105	31	32	11	179	0·22	0·09	0·14

Eleven double heterozygotes in F_3 gave :

Fertiles		Steriles			χ^2		
Yellow	White	Yellow	White	Total	**Ya—ya**	**Stp—stp**	(Linkage)
50	10	14	6	80	1·07	0·00	1·42

Thus there is no linkage between sterility and corolla colour genes.

(*iii*) *Sterility and leaf shape*

Two families in the F_3 of the above cross were found to segregate for leaf shape. Since both the original parents were homozygous for broad leaf (**ll**), the occurrence of these two families can only be ascribed to their being natural crosses. They actually proved to be heterozygous for leaf shape and sterility and exhibited the following two-factor distribution.

Fertiles		Steriles			χ^2		
Narrow	Broad	Narrow	Broad	Total	**L—l**	**Stp—stp**	(Linkage)
21	7	5	3	36	0·51	0·15	0·44

Selfed seed from 16 narrow-leaved fertile plants was used to grow as many families in the following year. Six families bred true to narrow leaf and six segregated into narrows and broads. (Four families with less than five plants in each were dropped out of consideration). The proportion of homozygous and heterozygous narrow families is close to expectation since χ^2 value calculated from the expected figure would be 1·5, and when $n = 1$, P would be between 0·80 and 0·20.

The segregating families gave :—

Narrows	Broads	Total
134	46	180

$\chi^2 = 0 \cdot 03$, $n = 1$, $P = 0 \cdot 90$-$0 \cdot 80$: Good fit

Out of these six families, only four segregated for sterility and their two-character distribution was as follows :—

	Narrows		Broads			χ^2		
Family	Fertiles	Steriles	Fertiles	Steriles	Total	**L—l**	**Stp—stp**	(Linkage)
406	3	2	4	1	10	3·33	0·13	0·40
408	6	5	5	2	18	1·85	1·85	0·22
417	29	12	8	1	50	1·30	0·03	1·07
425	40	6	12	2	60	0·09	4·35	0·03
Total	78	25	29	6	138	0·01	0·47	0·72

Thus sterility and leaf shape assort freely.

SUMMARY

(i) The sterility due to gene **stp** [Hutchinson and Silow, 1939] has been found to be caused by asynapsis.

(ii) This gene assorts freely with the genes controlling corolla colour anthocyanin and leaf shape in Asiatic cottons.

ACKNOWLEDGEMENTS

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REFERENCES

Beadle, G. W. (1930). *Cornell. Agric. Expt. Stn. Mem.* **129,** 1

Bergner, A. D.; Cartledge, J. L. and Blakslee, A. F. (1934). *Cytologia* **61,** 19

Clausen, R. E. (1931). *Amer. Nat.* **65,** 316

Huskins, C. L. and Hearne E. M. (1933). *J. Roy. Micr. Soc.* **53,** 109-17

Hutchinson, J. B. and Gadkari, P. D. (1935). *Ind. J. Agric. Sci.* **5,** 619-23

Hutchinson, J. B. and Silow, R. A. (1939). *J. Hered.* **30,** 461-4

Koller, P. C. (1938). *J. Genet.* **36,** 275-306

Ramanujam, S. and Parthasarthy, N. (1936). *Proc. Ind. Acad. Sci. Sec. B,* **2,** 80-7

Richardson, M. M. (1935). *J. Genet.* **31,** 119-43

A BRIEF ACCOUNT OF THE STUDIES ON THE HARMFUL AFTER-EFFECTS OF *CHOLAM* CROP ON COTTON*

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(With Plates III and IV and four text-figures)

ON the rain-fed black soils of the ' Tinnies ' † tract, farmers generally follow a four-course rotation of *cholam*→cotton→*cumbu*→cotton. Of these, *cholam* called locally *irungu* (*Sorghum dochna* var. 7 forma 2 *irungu*) is grown for fodder, while *cumbu* (*Pennisetum typhoideum*) and cotton (a mixture of *G. arboreum* var. *neglectum* forma *indica* H. & G. and *G. herbaceum* var. *frutescens* H. & G.) are respectively their main food and money crops. It is commonly observed there that cotton grown after *cholam* is paler in appearance, shorter in growth and poorer in yield than that coming after *cumbu* (Plate III). The average yield of *kapas* in the former is, according to the data collected at Koilpatti Agricultural Research Station during the past 31 years, 405 lb. as against 471 lb. recorded in the latter. This difference of 16 per cent in yield is of considerable value to the farmers depending on uncertain and deficient rainfall common in arid regions. The harmful effect of *cholam*-growing would, for the sake of convenience, be referred to in the following pages as ' *cholam* effect '.

HISTORICAL

It may be mentioned that the phenomenon of ' *cholam* effect ' is not peculiar to the ' Tinnies ' tract alone. It has been observed to exist under the conditions obtaining in Coimbatore, Salem and South Arcot districts of the Madras presidency, in parts of Bombay [Fletcher, 1912] and in the United Provinces ; and is said by American agronomists [Breazeale, 1924 ; Conrad, 1927, 1928, 1932, 1937] as a much-dreaded feature of *cholam* growing in their arid and semi-arid tracts. It has been the subject of somewhat extensive studies, particularly in America ; and very different hypotheses have been put forward concerning its nature and causes. One school of thought [Harper and Murphy, 1930 ; Holter and Fields, 1899] declared that the effect was due to the greater depletion of plant foods by the heavier-feeding *cholam* crop. It is interesting to note that this opinion is shared by the farmers of the 'Tinnies' tract also. Some workers [Mackinlay, 1931; Sewell, 1923; Ball, 1906; Miller, 1931], however, discountenanced the above view. A second group [Breazeale, 1924; Hawkins, 1925; Sewell, 1923] attributed the *cholam* effect to the production of an easily volatilizable toxic body during the decomposition of *cholam* residues, which killed all the micro-flora. Still another set of workers [Conrad, 1927; Wilson and Wilson, 1928] believed that the higher sugar contents of the *cholam* stubbles encouraged rapid multiplication of micro-organisms and created a nitrogen deficiency in the soil. All of them, despite these differences in their opinion, agreed that the *cholam* effect would be perceptible only on wheat and small grains, especially if they happened to be sown in winter soon after the harvest of *cholam*.

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* Full details will be published in the *Madras Agricultural Journal.*

† This is the name given to portions of Madura Ramnad and Tinnevelly districts of Madras province, where a variety of indigenous cotton called 'Tinnies' is being grown.

METHODS

Experiments were first conducted to verify whether any of the above theories would prove valid under the conditions obtaining in the tract under study. Investigations, with the object of finding out measures that would eliminate or correct the deleterious after-effects of *cholam* growing, were carried out from 1931 to 1937 at Koilpatti Agricultural Experiment Station situated in the heart of the 'Tinnies' tract. They were mostly agronomic in character and conducted on field plots laid out in the form of replicated randomized blocks and sometimes in split-plot fashion. Although the experiments covered a period of six years, conclusions were drawn from the data of seasons when the *cholam* effect was manifest. Such a precaution was necessary since the injurious effects were marked in years of good rainfall and since some of the years in the period of study were unusually droughty.

SUMMARY OF RESULTS

SOIL EXHAUSTION

If the hypothesis of soil exhaustion was applicable, it was apparent from *a priori* grounds that manuring either the cotton crop directly or the previous *cholam* crop should restore the depressed yield of succeeding cotton. Alternatively, if the production of total dry matter in *cholam* was reduced by wider spacing, the cotton yields should improve with the fall in dry matter. The results of experiments tried to elucidate these points negatived such a possibility. In both types of manuring, the depressing effects of *cholam* persisted (Table I).

The results of the above manurial experiments were of interest in another way. They proved that the theory of nitrogen deficiency in *cholam* plots put forward by McGeorge and Breazeale [1936] did not hold good on the black soils of Koilpatti. The cotton yields in the *cholam* plots were lower than those after *cumbu* in spite of their receiving 2 cwt of ammonium sulphate per acre.

Spacing experiments conducted during three seasons led to a similar conclusion. Cotton succeeding *cholam* sown in 36 in. spacing yielded as much as that following *cholam* spaced 6 in. (Table II). It was clear from these that soil exhaustion was not at the bottom of the trouble in question.

TABLE I
Depressing effect of cholam

		Yields of cotton in lb. per acre	
		Manuring cotton directly 1931-32	Manuring the previous crop 1933-34
No manure	After *cholam*	355	244
	After *cumbu*	411	452
Manured (112 lb. super + 224 lb. amm. sulphate)	After *cholam*	573	283
	After *cumbu*	690	517
Critical difference ($P = 0 \cdot 05$)		51	55

TABLE II
Yield of cotton succeeding cholam

	Cotton yields in lb. per acre		
	1934-35	1935-36	1936-37
After *cholam* spaced 6 in. between rows	521	362	232
Do. 18 in. between rows	512	393	223
Do. 36 in. between rows	522	539	221

N.B.—z-test not satisfied.

TOXICITY OF *CHOLAM* RESIDUES

Regarding the validity of this theory, investigations were of three kinds : one relating to the study of the effects of the stubbles only, the second to the decomposition of the roots and the third concerning the root excretions. In the first group of experiments, stubbles were removed from a few plots, while in others definite quantities of stubbles from other fields were added and incorporated. No differences were observed amongst the treatments (Table III).

TABLE III
Yield of seed cotton from plots with and without stubbles

	Yield of seed cotton in lb. per acre			
	1931-32	1932-33	1932-33	1933-34
Stubbles removed	504	556	..	..
Stubbles not removed	512	562	..	..
No stubbles added	..	..	816	470
221 lb. stubbles added	..	..	863	403
442 lb. do.	..	..	..	411
Critical difference ($P = 0 \cdot 05$)	15	55	64	69

In the second group of experiments, the toxicity of the *cholam* roots was sought to be eliminated as recommended by Breazeale [1924], by ploughing the residues early. The data collected pointed that the ploughing had not engendered any more beneficial effect than in the treatment ' not ploughed ' (Table IV).

TABLE IV

Yield of seed cotton from ploughed and unploughed plots

	Yield of seed cotton in lb. per acre	
	1932-33	1934-35
Not ploughed . . .	524	450
Ploughed . . .	563	493
Critical difference ($P = 0 \cdot 05$)	67	71

The question of toxic excretion of the roots was considerably more difficult to tackle by means of simple agronomic experiments on account of the underground location of the roots. Indirect evidence was therefore sought by studying the effects of the soil leachates on cotton plants raised in pots. Soil cores one foot in diameter and one foot in depth were removed from the first and second foot layers of the plots cropped with *cholam* and *cumbu*, as well as from fallow plots. Definite quantities of water were allowed to percolate through each core and the leachates were used to irrigate cotton plants raised in sand cultures. The plants showed no differences in growth. It was inferred that *cholam* soils did not contain leachable toxic products in such quantities as to be harmful to plant growth.

MOISTURE STUDIES

Apart from these, the low rainfall, the aridity of the climate obtaining in the ' Tinnies ' tract and the close spacing * adopted in the growing of *cholam* suggested that insufficiency in soil moisture might have acted as a limiting factor in the ' after-*cholam* ' plots. Such a possibility gained some strength from the reports made by Conrad [1927, 1937] and Breazeale [1924]. Very extensive studies were carried out for two seasons to settle this doubt. Moisture contents were estimated by drying, in steam oven, soil samples drawn periodically from the harvest of the previous crop till the bolling of the cotton in three sets of replicates of plots cropped with *cholam*, *cumbu* and horse gram, and also from neighbouring fallow plots. Samples of soil were from one-foot sections taken up to a depth of four feet by means of King's soil sampler. The data when analysed showed (Figs. 1-4) that the moisture contents increased with the depth up to the third foot and that the *cholam* plots, though they happened to be drier till the sowing of cotton, contained more moisture than the 'after-*cumbu*' plots throughout the entire growth period of the cotton crop, in spite of an appreciable lag noticed in the penetration of rain water into the lower layers in the former plots. It was thus made plain that the *cholam* effect could not have been brought about by deficiencies in the soil moisture.

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* The seed rate varies from 60 to 100 lb. per acre.

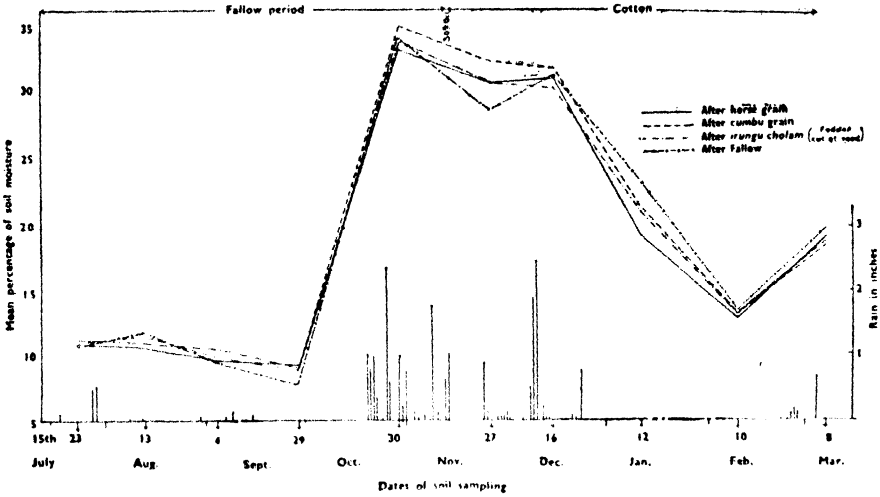


FIG. 1. Soil moisture experiments 1931-32 (first foot)

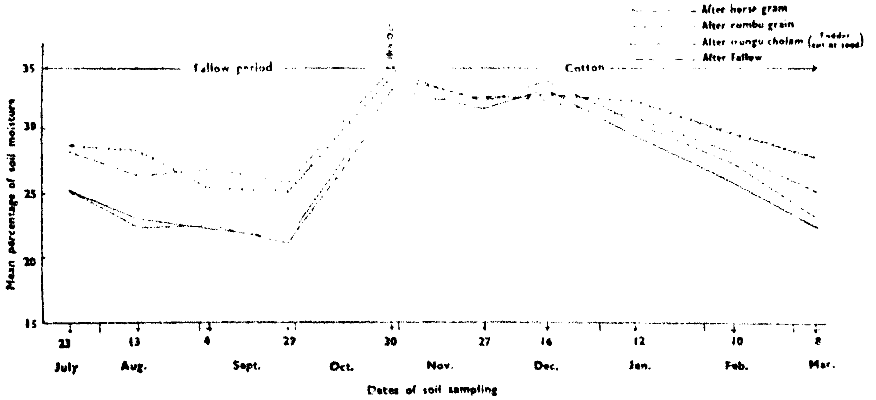


FIG. 2. Soil moisture experiments 1931-32 (second foot)

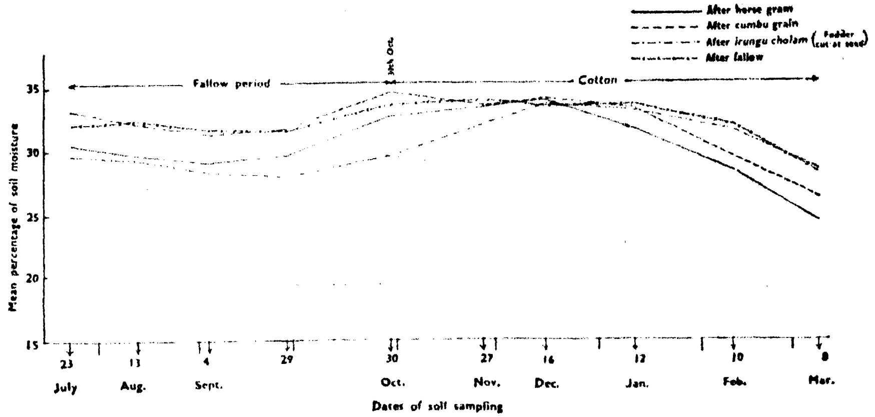


FIG. 3. Soil moisture experiments 1931-32 (third foot)

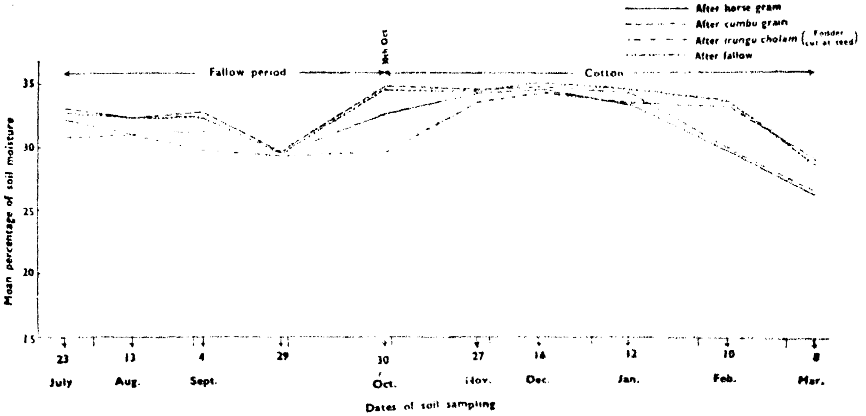


FIG. 4. Soil moisture experiments 1931-32 (fourth foot)

PECULIARITIES OF THE TRACT

The above finding suggest that the phenomenon of '*cholam* effect' under 'Tinnies' conditions is very much different from that met with in America. Besides, there are circumstances which add strength to this conclusion. In the tract under study the effects are felt on a deep-rooted cotton crop unlike on shallow-rooted cereals like wheat and small grains reported in America. In addition, a long summer fallow period having several intermittent showers of rain intervenes between the harvest of *cholam* and the sowing of cotton. The amount of stubbles usually left in 'Tinnies' conditions is also not considerable. It is perhaps only natural that with such distinct differences in the environmental complexes, the two phenomena are not similar in characters and in their relation to external changes.

NEW FEATURES

These investigations were, however, valuable in providing certain important clues about the nature of the *cholam* effect. For instance, it was found that if *cholam* was cut at shot blade stage, the usual depression in yield associated with the cottons raised on *cholam* plots was not observed ; if, on the other hand, the *cholam* crop was allowed to set seed, the deleterious effects increased with the duration of the seed-setting stage. This observation of the apparent dependence of the *cholam* effect on seed formation was later elaborated to get an insight into the probable causes of the phenomenon. The effects of some new treatments like 'sowing the *cholam* a month late' with the object of reducing the duration, 'cutting *cholam* at milk stage', 'removing *cholam* earheads soon after emergence', 'cutting *cholam* at shot blade stage', 'harvesting *cholam* at shot blade and ratooning', and 'sowing *cholam* thick' to reduce seed setting, and 'retaining the *cholam* crop for two months' more than the normal date of harvesting were studied. The results are set out in Table V.

TABLE V

Yield of seed cotton after cholam *cut at different stages*

	Yield of seed cotton in lb. per acre	
	1934-35	1937-38
After *cholam* cut at seed (control) . . .	417	407
After *cholam* cut at shot blade	626	507
After *cholam* cut at flower	..	556
After *cholam* cut at milk stage	..	457
After *cholam* cut 2 months after seed setting .	..	395
After *cholam* cut with earheads removed after emergence	495	452
After *cholam* sown thick and cut at seed . .	523	..
After *cumbu*	..	661
Critical difference ($P = 0 \cdot 05$)	100	89

It was apparent from Table V that the treatments '*cholam* cut at shot blade' and '*cholam* sown thick' had distinctly better after-effects than the control treatment '*cholam* cut at seed', and that the better of the two, viz. '*cholam* cut at shot blade' was yet behind the cotton yields obtained in 'after-*cumbu*' plots. A point of interest was that the variant *cholam* retained for two months after seed setting gave as much yield of cotton as that from the control '*cholam* cut at seed' plot, indicating thereby that the retention of *cholam* crop beyond the seed-setting stage did not enhance the harmful effect.

The effects of ratooning, which were studied in another series of experiments but with the same object in view, are presented in Table VI.

TABLE VI

Effects of ratooning

	Yield of seed cotton per acre in plots after					
	Cholam cut at seed	*Cholam* cut at shot blade	First *cholam* cut at shot blade		Average	Critical difference
			Ratoon cut at flower	Ratoon cut at seed setting		
After *cholam* sown at normal season	699	749	573	440	615	58
After *colam* sown a month later	669	796	583	501	639	
Average	684	773	581	471		
Critical difference ($P = 0{\cdot}05$)	83					

It was seen from these that the treatment ' ratoon cut at seed setting ' reduced the cotton yields more than the ' ratoon cut at flower'. It ruled out the possibility of *cholam* seed-setting as being the cause of the reduced yields, since both types of ratoons did not set seed in spite of retaining them for a long time. The question of duration was also excluded as a possible reason, since the treatment ' ratoon cut at flower ' had a lowered yield, in spite of its being of the same duration as the treatment ' *cholam* cut at seed '. The operation of ratooning, therefore, appeared to bring about the depression in yield. It is common knowledge that ratooning a crop stimulates its roots to spread further, and it could therefore be taken that penetration of *cholam* roots in the lower layers was responsible for the fall in the yield of seed cotton.

The above clue supplied a good explanation for the entire phenomenon of ' *cholam* effect '. The *cholam* crop comes to ear soon after the cessation of the north-east monsoon when the roots are only within the upper layers. When clear weather sets in, and when the soil moisture at the top layers dries up, the roots penetrate into lower depths ; and if the *cholam* is ratooned, the roots go further down. As the seeds set, root absorption ceases to a great extent. If a comparison is made with the degree of penetration of roots at different stages of *cholam* growth and the disposition of injurious salts in the soil at different depths (Table VII), a suggestive relationship is found. So long as the roots are in the top layers containing no injurious salts, the deleterious effect is not visible as evidenced by the performances of plots with *cholam* cut at shot blade treatments. When the roots enter the lower regions of the soil profiles containing the injurious salts, the yields of the succeeding cotton are affected to the extent of penetration of the roots. When once the root absorption stops as in the ' beyond-the-seed-setting ' stage, further addition to the *cholam* injury is not made.

TABLE VII

Koilpatti black soil profile at different depths

(On percentage basis)

No.	Head of analysis	0—1 ft.	1—2 ft.	2—3½ ft.	3½—4½ ft.	4½—6 ft.	6—7 ft.	7—8 ft.
1	Lime (CaO) . .	0·0062	0·0016	0·3300	0·3400	0·3300	0·0890	0·0860
2	Magnesia (MgO) .	Trace	Trace	0·0610	0·0880	0·0860	0·0320	0·0300
3	Bicarbonate (HCO_3) .	0·0310	0·0530	0·0190	0·0210	0·0210	0·0300	0·0260
4	Carbonate (CO_3) .	0·0060	...	...	...	...	...	...
5	Sulphate (SO_4) . .	0·0028	0·0110	0·0760	1·0370	1·1700	0·7000	0·6500
6	Chloride (Cl) . .	0·0050	0·0060	0·0060	0·0070	0·0080	0·0100	0·0230
7	Total solids . .	0·0670	0·0950	1·4150	1·9200	2·1400	1·2900	1·2300
	Calculated salts—							
	Calcium bicarbonate	...	...	0·025	0·028	0·028	0·040	0·035
	Calcium carbonate .	...	...	...	...	...	...	...
	Calcium sulphate .	...	...	0·79	0·81	0·78	0·18	0·18
	Calcium chloride .	...	...	...	...	...	...	...
	Magnesium bicarbonate	...	...	...	...	...	...	...
	Magnesium carbonate	...	...	...	...	...	...	...
	Magnesium sulphate	...	...	0·182	0·26	0·26	0·095	0·089
	Magnesium chloride	...	...	...	...	...	...	...
	Sodium bicarbonate .	...	...	...	...	...	...	...
	Sodium carbonate .	...	...	...	...	...	...	...
	Sodium sulphate .	...	...	0·32	0·69	0·95	0·94	0·86
	Sodium chloride .	...	...	0·0099	0·012	0·013	0·017	0·038

PHYSICAL CHARACTERS OF THE *CHOLAM* SOILS

Moreover, field observations of soils made during a number of seasons pointed out that the soils of a *cholam* field were hard to plough and cracked poorly in normal seasons and were more subject to the erosive forces of rains. They showed in addition a tendency to absorb rains more slowly and retain moisture for a longer period. These indicated a deterioration in aggregate formation. Laboratory investigations confirmed the deductions. The percolation studies showed that water passed through more slowly in the *cholam* soils than in those of *cumbu* plots, which became more appreciable with the increase in the number of leachings. The percolates from *cholam* soils were turbid and took more time for the setting of the soil suspensions. In addition the *cholam* soils were found to have higher soil dispersion coefficients than those of *cumbu* under similar conditions of moisture. These undesirable physical properties indicated reduction in pore space due to deterioration in the soil structure.

In the opinion of Russell [1938] such changes in the soil structure in the field would be accountable on the basis of changes either in the total clay content or in the ionic composition. Both these aspects were studied. It was found that there was practically no change in the total contents of clay.

STUDIES IN IONIC CONTENTS

The soils at two depths were next analysed during three periods during the first year according to the methods outlined by Chapman and Kelly [1932]. The results indicated that the *cholam* plots contained more exchangeable soda than those of *cumbu*, and that soda increased with crop growth.

TABLE VIII (*a*)

Exchangeable soda in milli-equivalents per 100 gm. of soil

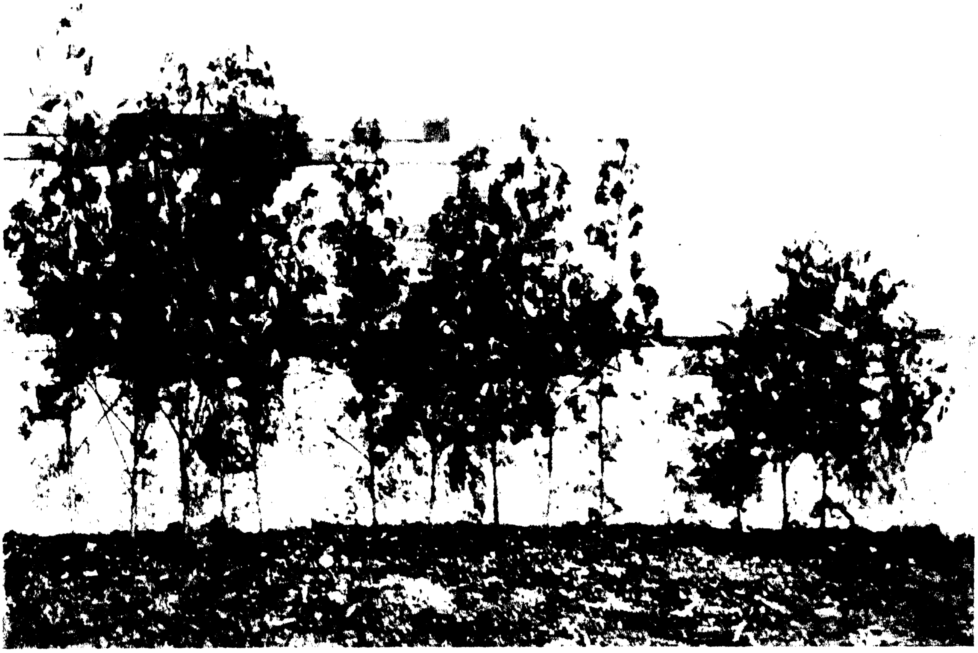
No.	Growth period	Average of all depths	Soil depths	Average of all crops and growth period	Average of all depths and growth period		
					Irungu	*Cumbu*	Fallow
1	Before the sowing of cereals, Sept. 1935	6·4227	1. Top 6 in.	5·2657	9·7046	7·6311	6·5954
2	The cereals 6 weeks old, Nov. 1935	8·0300	2. II 6 in.	5·1881			
3	At the shot blade stage of *cholam*, Dec. 1935	8·5247	3. III 6 in.	6·4619			
4	After the harvest of *cholam*, Feb. 1936	9·2380	4. IV 6 in.	10·3724			
5	Mid-summer—no crop period, June 1936	8·1100	5. V 6 in.	12·5971			
6	Before the sowing of cotton, Sept. 1936	7·8987					
7	When cotton was two months old, Dec. 1936	7·6147					
	Critical difference	1·240		1·035		0·791	
	Conclusions .	4, 3, 5, 2, 6, 7, 1		5, 4, 3, 1, 2	*Irungu* > *Cumbu* > Fallow		

TABLE VIII (*b*)

Values of exchangeable soda at depths between 12-18 in.

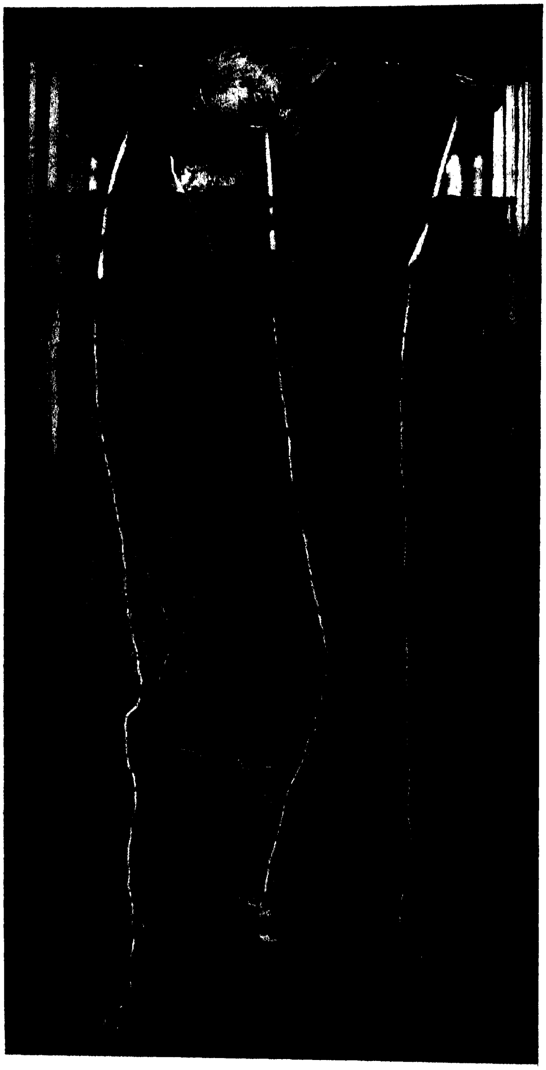
		Cumbu	*Cholam*	Fallow
		m. e.	m. e.	m. e.
1	Before the sowing of cereal in September .	2·85	4·00	3·91
2	When the crop was 6 weeks old . .	6·71	7·70	4·00
3	At shot blade stage.	8·03	8·32	5·10
4	At the time of harvest of cereals . .	8·46	10·08	6·09
5	Mid-summer (no crop period) . .	7·16	10·60	6·22
6	Before the sowing of cotton . . .	4·93	9·99	4·49
7	Two months after the sowing of cotton .	4·32	8·57	4·17

Conclusions on the average of *cumbu* and *cholam*— } 4, 3, 5, 2, 6, 7, 1 *Irungu*> *cumbu*>fallow



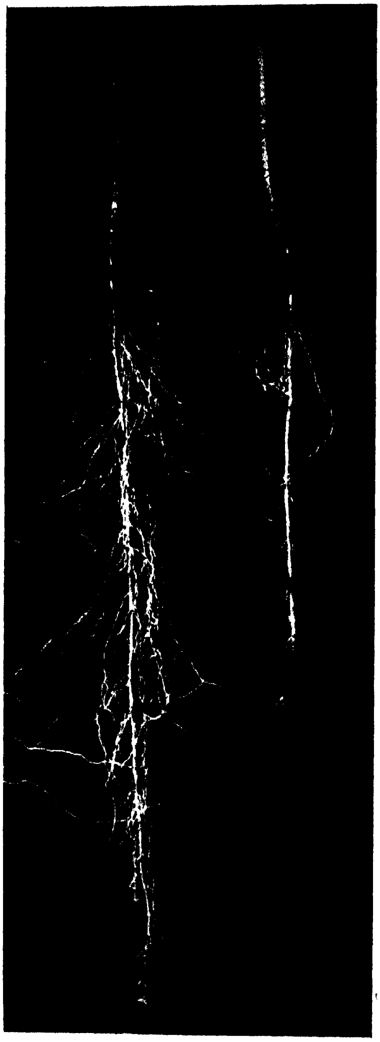
After pulse After *cumbu* After *cholam* fodder set seed

Growth of cotton



Soda in milli-equivalents 1·09 4·26 11·14

FIG. 1. Seedlings 13 days old



Gypsum treated Control (after *cholam* fodder set seed)

FIG. 2. Root-system in chimney culture

To elucidate this point further, soil samples were drawn during the next season from plots cropped with *cholam* and *cumbu* and also from fallow plots. at seven definite periods beginning with the fallow season prior to the sowing of the cereals and ending with the growing phase of the succeeding cotton. Estimations were made for the total exchangeable bases, calcium, magnesium, potassium and sodium ions. Very little differences were noticed in the total exchangeable bases, but a decrease in magnesium and a corresponding increase in the exchangeable soda was marked in the *cholam* soils. The data for sodium ion contents are summarized in Table VIII (*a*) and (*b*).

The sodium ion contents, especially those of the top third 6 in. layer, showed a characteristic pattern of ionic concentration varying with the time of analysis. Samples taken just prior to the sowing of cereals exhibited no significant differences between the plots. But in November, when the crops were six weeks old, their soils showed higher soda contents than the fallow. At the time of *cholam* harvest, they reached the maximum concentration. In June next, the soda contents started to decline. By September, just before the sowing of cotton, *cumbu* plots recorded a greater fall than those of *cholam*. When the cotton crop was two months old, *cumbu* plots contained exchangeable soda only as much as in fallow plots, while the *cholam* plots continued to maintain a higher amount.

The well-marked physical conditions of *cholam* soils, viz. lower cracking earlier erodability, reduced percolation, higher dispersion values, and cloddy condition, all now found an acceptable explanation in the increased alkalinization exhibited by such soils. But one would be inclined to doubt whether after all the increase in the soda of the order of 3 to 4 m. e. (milli-equivalents) would cause a depression in the yield of cotton to the extent of 16 per cent. But the consistency of the observations during more than one season gave it the strength of real existence. Further, evidences from other experiments conducted on the efficiency of small increments in sodium content on causations of appreciable changes in physical conditions of soils also became available. When cotton seedlings were raised in soils differing in replaceable sodium contents, pronounced differences in the development of root-systems were noticed even when the differences in sodium contents were as small as those observed between 'after *cumbu*' and 'after *cholam*' plots (Plate IV, fig. 1). The development of lateral roots was inhibited to a greater extent when the soda contents in the soil were higher. Apart from the above, Ratner [1935] found that an increase of 5·1 milli-equivalents in replaceable sodium affected considerably the physical properties of the soil in pots and concluded that the deleterious effect of exchangeable soda might be perceptible in practice in soils even with lower amounts than under the conditions of pot culture. Profile studies of the soils at Koilpatti (Table VII) pointed out that sulphates of calcium, magnesium and sodium were present to a higher degree from 2 to 6 ft. depths and that the concentration of sodium sulphate at depths below 3 ft. 6 in. was above 0·75 per cent limit of tolerance given by Hilgard [1936] for the growth of agricultural crops in heavy soils. Dastus [1938] found that concentrations of 0·08 per cent and upwards in sodium salts proved harmful to cotton. The soil profiles at 4½-6 ft. depths at Koilpatti showed higher concentrations than this limit. The surprise was that a fairly good growth of cotton and heavy yields of *cumbu* were obtained in these soils despite the high concentration of injurious salts. Possibly large quantities of gypsum met with in the lower layers of these soils reduced the harmful effects to a considerable extent.

It may, however, be pointed out that certain lacunae still exist for a complete understanding of the phenomenon on the basis of the above observations. The two facts that the *cholam* effect lasts for a single season and that the sodium when once it enters the soil complex is not easily removable, particularly under arid conditions, are not reconcilable with one another. The data on the exchangeable composition of the soils and its periodical changes do show the desired reversal of the sodium increase, but they need further confirmation. Final conclusions on this point should wait till more light on the rational mechanism for the reversal phenomenon is obtained.

TRIAL OF CORRECTIVES

The evidences of soda being in excess in the soils cropped with *cholam* suggested the application of correctives generally used to reclaim alkaline soils. When they were actually tried for two seasons on both *cholam* and cotton crops, the results indicated that none of them were really effective against the *cholam* effect under the conditions tested (Table IX).

TABLE IX

Effect of correctives on cotton yield

	Weight of seed cotton per acre (lb.)	
	Manuring done directly to cotton, 1936-37	Manuring done to the previous *cholam*, 1937-38
No fertilizer	261	599
Magnesite	199	600
Magnesite *plus* sulphur	228	608
Magnesium sulphate	241	569
Magnesium sulphate *plus* sulphur	211	566
Gypsum (local deposit)	284	599
Gypsum *plus* sulphur	234	625
Sulphur	222	629
Critical difference	46	65

The effect of molasses, which has been declared to be a good corrective for alkalinity by Dhar [1936], was studied for two seasons. In one season when the *cholam* effect was not perceptible, the incorporation of molasses increased the yield of seed cotton distinctly, but in the second year when the *cholam* effect was evident, the application did not induce any distinct response (Table X). The divergence in the results coupled with prohibitive cost of the molasses did not encourage further trials.

TABLE X

Effect of molasses on the yield of cotton seed

	Yield of seed cotton in lb. per acre	
	1936-37	1937-38
No molasses	263	709
Molasses	383	661
Critical difference	94	82

It was, however, made clear that the failure of the correctives to improve the *cholam* effect should not be taken as an indication of the non-existence of alkalinity in such soils, because when such soils were mixed with gypsum and used for raising cotton seedlings in chimneys, the root development was as good as in *cumbu* soils (Plate IV, fig. 2). The absence of response to the correctives under field conditions should be deemed to be due to the operation of unfavourable factors. Unfortunately the last three seasons, when the manures were tried, had erratic rainfall, with the result that the rains received at one time were not sufficient to carry the correctives down to the layers where the injurious alkaline salts were actually present.

TRIAL OF ALTERNATIVE FODDERS

Trials were also made to find out whether the *cholam* crop—the cause of the trouble—could be replaced by more beneficial crops. Several varieties of legumes, teosinte and *cumbu* were tested, but none of them succeeded to give as much fodder as was provided by the *cholam*. Different varieties of *cholam* were also compared. Their tonnage and palatability too were far behind those of the *irungu* variety grown in the tract. Harvesting *irungu cholam* at shot blade stage did not engender the injurious after-effects ; but that practice could not be adopted for two reasons. Firstly it provided only two-thirds of the fodder supplied by harvesting it at seed. Secondly the period of harvest synchronized frequently with wet weather which did not permit the drying of the stalks.

OTHER DEVICES

The beneficial effects of legumes on non-legumes grown in association with them were then sought to be utilized to minimize the *cholam* effect. The effect of the mixing of several pulses with *cholam* as well as with cotton were tested. In all the trials, the harmful after-effect of *cholam* continued to persist. In certain cases, associated cropping, like mixing black gram (*Phaseolus mungo*) with cotton, proved injurious.

Concurrently attempts were made, taking the clue from the normal agronomic practice of using a higher seed rate in crops to be grown in fertile and deteriorated soils, to test the efficacy of thick sowing of cotton on *cholam* effect. In all the three years of trial, distinct increases in the yield of seed cotton were obtained as a result of this practice (Table XI).

TABLE XI

Yield of normal and thick-sown cotton

	Yield of seed cotton in lb. per acre		
	1934-35	1935-36	1936-37
Normal sown .	422	258	236
Thick sown . .	495	286	259
Critical difference .	55	77	16·1

There was uniformity in the response to thick sowing, both in good and droughty years. This practice of using 15 lb. of seed rate in the place of 10 lb. used at present in the sowing of cotton could therefore be recommended for adoption on all fields cropped with *cholam*.

Mosseri [1931] stated that the absence of alkali troubles in the stiff clay soils of Egypt was due to the observance of summer fallow which permitted the land to crack widely and the deleterious salts to be deposited in the form of encrustations on the outside of clay particles, and that these salts were later on washed down by the heavy irrigations. This suggested that the general practice of the farmer of the 'Tinnies' tract to plough the land six to eight times prior to the sowing of cotton would have prevented the soils from cracking widely and from forming encrustation of the salts on the soil particles. Experiments were conducted to study the effect of keeping the land unploughed till the sowing of cotton. The results obtained during four seasons (Table XII) pointed out that the yields in 'not-ploughed' plots were only as good as those that were ploughed.

	Yield of seed cotton in lb. per acre			
	1934-35	1935-36	1936-37	1937-38
Ploughed	450	244	396	522
Not ploughed	453	302	380	505
Critical difference ($P=0{\cdot}05$) .	81	38	18·9	65

These observations, though they did not conform to expectations based on Egyptian experience, were useful to show that some of the preparatory operations could be dispensed with, reducing thereby the cost of cultivation of cotton, which would be an indirect gain to the farmer.

SUMMARY

The results obtained may be summed up thus :

(*a*) The diminished yield of cotton obtained in the tract on fields cropped with *cholam* during the previous year is found to be caused neither by lack of soil moisture, nor by exhaustion of soil nutrients, nor by the presence of toxic products of decomposition.

(*b*) The harmful effects could not be improved by the application of manures, the reduction of plant population or by mixing *cholam* with pulses.

(*c*) Seed setting and duration of *cholam* were observed to influence the intensity of the deleterious effects of *cholam* cropping, since the *cholam* effect was not manifest in the crop cut at shot blade. This phenomenon could be ascribed to the normal penetration of the *cholam* roots into the alkaline regions of the soil below the second foot.

(*d*) The growing of both *cumbu* and *cholam* disturbed differently the sodium ion contents of the soil. In soils cropped with *cholam*, the rise of replaceable sodium was greater with the growth of crop, but its later decline was much slower than that observed in the case of *cumbu* plots. As a consequence former soils were left more alkaline at the time of cotton sowing, which condition would appear to be responsible for the lower yields recorded after *cholam* crops.

(*e*) Correctives for alkalinity could not give conclusive results owing to unfavourable seasonal conditions. It was however inferred that their application in the lower layers might show better response.

(*f*) *Cholam* could not be replaced by other fodders.

(*g*) Ploughing experiments showed that these soils were not benefited by cultivating them prior to the sowing of cotton. A saving in the cost of cultivation might be effected by reducing the preparatory cultivation to the minimum.

(*h*) Thick sowing of cotton improved the yields of cotton in ' after *cholam* ' plots, both in good and poor seasons of rainfall.

ACKNOWLEDGEMENTS

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REFERENCES

Breazeale, F. J. (1924). *J. Amer. Soc. Agron.* **16,** 689-700

Ball, C. R. (1906). *U. S. A. Dep. Agric. Farm Bull.* **246**

Chapman and Kelly (1932). *Imp. Bur. Soil Sci. Tech. Comm.* No. **30**

Conrad, J. P. (1927). *J. Amer. Soc. Agron.* **19,** 1091, iiii

——— (1928). *J. Amer. Soc. Agron.* **20,** 1211-34

——— (1932). *J. Amer. Soc. Agron.* **24,** 316-22

——— (1937). *J. Amer. Soc. Agron.* **29,** 367-78 ; 1014-22

Dastur, R. H. (1938-39). *Punjab Physiological Scheme Prog. Rep.*

Dhar, A. L. (1936). *Nature* 629

Fletcher (1912). *J. Agric. Sci.* **4,** 245-7

Harper and Murphy, H. F. (1930). *Expt. Sta. Rec.* **61,** 730

Hawkins, R. S. (1925). *J. Amer. Soc. Agron.* **19,** 91-2

Hilgard, E. W. (1906). *Soils* : The Macmillan Company

Holter, G. L. and Fields, J. (1899). *Oklahama Sta. Bull.* **37,** 17-8

Mc George, W. T. and Breazeale, J. F. (1936). *Cali Citrogr.* **21,** 246-7

Miller, E. C. (1931). *Text-book of plant physiology*, pp. 129-38 (1931 edn.)

Mackinlay, A. D. (1931). *J. Amer. Soc. Agron.* **23,** 844-9

Mosseri, V. M. (1931). Quoted by Keen (*The physical properties of soil*): Longmans Green & Co.

Ratner, R. I. (1935). *Soil. Sci.* **40,** 459

Russell, E. W. (1938). *Sci. Progress* **32,** 128, 660-76

Sewell, M. C. (1923). *Bot. Gaz.* **75,** 1-26

Wilson, R. B. and Wilson, J. K. (1928). *J. Amer. Soc. Agron.* **20,** 747-54

*A PRELIMINARY NOTE ON THE EFFECT OF ENVIRONMENT ON THE QUALITY OF PUNJAB-AMERICAN 289F/43 COTTON

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INTRODUCTION

THE Punjab-American 289F/43 is a selection from a strain 168F produced by Milne. In 1925, one off-type plant was selected from this strain. This plant proved to be a natural hybrid and during 1926 to 1933, several progenies of this plant were under observation and trial. These progenies while differing in minor morphological characters, had several very desirable features in common. The most notable of these were early-maturing habit, good opening of bolls and long lint. After careful field trials the present strain was selected for general propagation in 1934. The area under this strain expanded very rapidly and in 1938-39 it was estimated to be about one lakh of acres, chiefly in the Lower Bari Doab Canal Colony and the inundation tracts in the south-west of the province.

289F/43 is a very drought-resistant and high-yielding variety, the lint of which has been adjudged, at the Technological Laboratory, Matunga, Bombay, as capable of spinning up to 35/40 standard warp counts spun with medium twist in different years. The samples for these spinning tests have all been drawn from the produce of the seed multiplication area at the Cotton Research Farm, Risalewala, where the crop is grown under very good conditions and expert supervision. The seed produced at this farm is then grown at the Seed Farm, Risalewala, where also the crop is carefully rogued and the ginning of the *kapas* is carried out at the experimental ginnery where there is no chance of seed contamination. The seed so produced is passed on to the big estates, where also some control is exercised by the Punjab Department of Agriculture. The ginning at this stage is, however, done in commercial ginneries. This seed is purchased by the Agricultural Department for sale to the cultivators. Thus it will be seen that there are four distinct stages of propagation of this vareity, viz. the seed multiplication area at the Cotton Research Farm, Risalewala, Seed Farm, Risalewala, the big estates and the general cultivator. While there is rigid control during the first two stages and partial control during the third stage, no control whatever is possible when the seed passes on to the cultivators of the province. From the point of view of the trade, however, the crop produced by the cultivators is the most important as by far the biggest bulk of the supplies of cotton which finds its way into the various channels of trade comes from them. It was, therefore, considered desirable to find out the variations, if any, in the fibre properties of 289F/43 as it passes on from one stage of propagation to another and also the effect of environment during the fourth stage.

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*Read before the Indian Science Congress, Madras, January, 1940

It is well known that the quality of lint of the various pure strains in the Punjab varies with the locality of growth. The present investigation, therefore, assumes an additional importance, as it will provide some very useful information to the trade.

PREVIOUS LITERATURE

Turner [1929] carried out a large number of spinning tests on Punjab-American 4F and 289F and the improved Mollisoni grown in different parts of the province. The spinning performance in terms of highest standard warp counts of these cottons varied from 16's to 24's for 4F, from 38's to 44's for 289F and from 5's to 8's for Mollisoni. Barre [1938] carried out what he called a regional variety study and planted 16 varieties of cotton from the same seed-stock at 14 places across the cotton belt of the United States of America and seven varieties at four localities in the irrigated tract of the south-west for three years in succession. He found that there was seldom more than 1/8 inch difference in staple length of any particular variety when grown in the Mississippi Delta under optimum moisture conditions or when grown under the extremely arid conditions of 1935 in Oklahoma and west Texas. From his extensive data he concluded that inheritance and soil moisture were the two factors determining staple-length and that inheritance was the more important of the two.

MATERIAL AND METHODS

For the purpose of the present investigation, the crop raised at the Cotton Research Farm, Risalewala, represents the first stage of propagation, that raised at the Seed Farm, Risalewala, the second stage and that from Sardar Bahadur Sardar Ujjal Singh's Farm, Mian Channu, the third stage. The following 12 places scattered all over the Canal Colonies and the inundation tracts of the south-west were selected as being representative of the fourth stage :

(i) Chiniot
(ii) Khanewal
(iii) Kot Adu
(iv) Okara
(v) Shorkot
(vi) Vihari
(vii) Jhang
(viii) Sangla Hill
(ix) Mithalak Stud Farm, Sargodha
(x) Montgomery
(xi) Sargodha
(xii) Nankana Sahib

The samples were collected in 1936 and *kapas* from the middle picking of 25 plants each from the first and the second stages, 50 plants from the third stage and 10 plants from each of the 12 places of the fourth stage was picked separately for each plant. The *kapas* from each plant was ginned very carefully with the laboratory hand roller gin and the lint was tested for the following characters :

(i) Mean fibre-length,
(ii) Mean fibre-weight per unit length at 70 per cent relative humidity, and
(iii) Fibre maturity.

The mean fibre-length was determined with Ball's Sledge Sorter [1921], The mean fibre-weight per unit length, which is a measure of the fineness of staple, was obtained after the whole fibre method of Ahmad [1933]. The fibre maturity was determined according to the method described by Gulati and Ahmad [1935], and for this purpose the fibres were mounted on the ' maturity slides ' devised by Ahmad and Gulati [1936].

EXPERIMENTAL RESULTS

The results obtained were analysed statistically by Student's *t*-method for determining the significance or otherwise of the differences in the averages of the lint characters between the first and the other stages. As some of the samples received from 11 out of the 12 places in the fourth stage were not found to be typical of 289F/43 (probably due to admixture with seed of other varieties in commercial ginneries), the analysis was carried out in two stages. One in which all the samples were considered irrespective of the variety to which they belonged and the other in which only those samples as belonged to 289F/43 were considered. The results obtained are shown in Table I.

CONCLUSION

This preliminary study of the problem has revealed certain very interesting features, and it was, therefore, considered desirable to bring these results to the notice of other workers on cotton in India. It is thought that similar studies made on other commercial varieties of cotton will prove very useful not only to the worker in the laboratory but also to the members of the trade. The conclusions are as follows :

(*a*) The average mean lengths and percentages of mature fibres for samples from the second and the third stages were significantly higher than for samples from the first stage, while the average mean fibre-weights per unit length were not significantly different from one another. This showed that the fibres in the second and the third stages were finer than those in the first stage since there was no significant difference in mean fibre-weight per unit length in spite of a significant increase in maturity.*

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*At a conference held in Bombay, Dr Nazir Ahmad suggested an alternative possibility that the constancy of the fibre-weight might be due to a change in the distribution of the percentages of mature, half-mature and immature fibres. The results were studied with this suggestion in mind, and it was found that the above conclusions were still true.

TABLE I

STAGE	No.	PLACE OF ORIGIN	ALL SAMPLES							SAMPLES OF 289F/43 ONLY						
			No. of samples	Average mean length (cm.)	Difference from the first stage	Average mean fibre-weight* (10^{-6} gm.)	Difference from the first stage	Average percentage of mature fibres	Difference from the first stage	No. of samples	Average mean length* (cm.)	Difference from the first stage	Average mean fibre-weight* (10^{-6} gm.)	Difference from the first stage	Average percentage of mature fibres	Difference from the first stage
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
I	1	Cotton Research Farm, Risalewala	25	2·3112	...	1·6628	...	60·104	...	25	2·3112	...	1·6628	...	60·104	...
II	14	Seed Farm, Risalewala	25	2·404	—0·0928†	1·6532	0·0096	67·548	—7·444†	25	2·404	—0·0928†	1·6532	0·0096	67·548	—7·444†
III	15	Sardar Bahadur Sardar Ujjal Singh's Farm, Mian Channu	50	2·445	—0·1338†	1·705	—0·0422	64·88	—4·776**	50	2·445	—0·1338†	1·70[illegible]	—0·0422	64·88	—4·776**
IV	2	Chiniot	10	2·345	—0·0338	1·863	—0·2002†	64·4	—4·296	6	2·326	—0·0155	1·923	—0·2605†	64·816	—4·713
	3	Khanewal	10	2·476	—0·1648†	1·820	—0·1572†	69·6	—9·496†	5	2·444	—0·1328†	1·916	—0·2532†	73·26	—13·156†
	4	Kot Adu	10	2·132	0·1792†	1·801	—0·1382**	58·17	1·934	8	2·115	0·1962†	1·850	—0·1872†	58·55	1·554
	5	Okara	10	2·161	0·1502†	1·944	—0·2812†	65·82	—5·716	4	2·092$_{8}$	0·2187†	2·010	—0·3472†	64·7[illegible]	—4·671
	6	Shorkot	10	2·243	0·0682**	1·727	—0·0642	62·6	—2·496	9	2·24	0·0712**	1·714	—0·0516	62·24	—2·136
	7	Vihari	10	2·241	0·0702†	2·028	—0·3652†	71·36	—11·256†	7	2·205$_{7}$	0·1055†	2·075$_{7}$	—0·4129†	74·486	—14·382†
	8	Jhang	10	2·295	0·0162	1·845	—0·1822†	66·46	—6·354	5	2·334	—0·0228	1·678	—0·0152	68·78	—8·676**
	9	Sangla Hill	10	2·408	—0·0968†	1·908	—0·2452†	70·55	—10·446†	6	2·405	—0·0938†	1·806	—0·1439**	67·6	—7·496**
	10	Mithalak Stud Farm, Sargodha	10	2·334	—0·0228	1·561	0·1018**	47·94	12·164†	7	2·318$_{6}$	—0·0074	1·524$_{1}$	0·1385**	48·629	11·475†
	11	Montgomery	10	2·366	—0·0548	1·873	—0·2102†	67·2	—7·096**	6	2·311$_{6}$	—0·0005	1·830	—0·1672†	64·6	—4·563
	12	Sargodha	10	2·284	0·0272	1·542	0·1212**	51·05	9·054**	8	2·261$_{2}$	0·0499	1·545	0·1178**	49·587	10·516**
	13	Nankana Sahib	10	2·319	—0·0078	1·707	—0·0442	64·14	—4·036	10	2·319	—0·0078	1·707	—0·0442	64·14	—4·036

*At 70 per cent relative humidity
**Significant at 5 per cent level
†Significant at 1 per cent level

(*b*) The samples from the Mithalak Stud Farm and the *zamindari* farms at Sargodha were somewhat exceptional in that they possessed low maturity with correspondingly low mean fibre-weights per unit length as compared with the samples from the first stage even though the mean lengths were not significantly different from one another. These results fit in with the agricultural field trials which have shown that this part of the Lower Jhelum Canal Colony is not suitable for the growth of 289F/43. These samples were not, therefore, considered further.

(*c*) The average mean fibre-weights per unit length and percentages of mature fibres for samples from the remaining 10 places were all greater than for samples from the first stage. Samples from Kot Adu were an exception to this general observation since the percentage of mature fibres was not significantly different. Of these 10 places, samples from Chiniot, Khanewal, Sangla Hill, Montgomery and Nankana Sahib possessed a greater average mean length. Those from Kot Adu, Okara, Shorkot, Vihari and Jhang were shorter in staple. Of the former five places, samples from Khanewal and Sangla Hill only were significantly longer, while of the latter five only those from Kot Adu, Okara, Shorkot and Vihari were similarly shorter.

The most interesting part of these observations is brought out here. For samples from Kot Adu and Okara, the percentage of mature fibres was not significantly different from that for the first stage ; and a significant decrease in their staple-length was accompanied by a significant increase in their mean fibre-weight per unit length. In this case it seems that the environmental conditions obtaining were rather unfavourable for an increase in the length of the fibre, but were favourable for an increase in the mean fibre-weight per unit length. Since the percentage of mature fibres practically remained the same, the effect of the increase in mean fibre-weight per unit length was to make the lint coarse.

For samples from Khanewal and Sangla Hill, there was a significant increase in fibre maturity over the first stage ; and a significant increase in the staple-length of these samples was still associated with a significant increase in their mean fibre-weight per unit length. It is apparent that the conditions which prevailed here had been favourable not only to an increase in the staple-length but also to increases in the mean fibre-weight per unit length and maturity. Since the increase in mean fibre-weight per unit length was associated not only with an increase in maturity but also with an increase in staple-length, it is highly probable that the lint in this case was finer.

The samples from Vihari were further characteristically different from the rest in that a significantly large increase in maturity, combined with a large decrease in staple-length, resulted in a large increase in mean fibre-weight per unit length. In this case the lint had apparently grown very coarse.

(*d*) These results indicate that the lint of 289F/43 from the fourth stage showed a tendency, in general, towards coarseness when compared with the lint from the first stage, excepting the samples from Khanewal and Sangla Hill, where the lint either continued to be of the same fineness as that of the first stage, or more probably was of greater fineness. The staple-lengths of these samples are ranged equally on both sides of the value for the first stage while the fibre maturity is uniformly higher excepting for a non-significant decrease in samples from Kot Adu.

SUMMARY

The propagation of the Punjab-American cotton 289F/43 was divided into four stages and the effect of stage of propagation on the quality of lint was traced from stage to stage. It was found that the staple-length and maturity of lint from the second and the third stages showed an improvement over those of the first stage, while the mean fibre-weight per unit length was almost constant. This improvement was not maintained in the samples from the fourth stage excepting those from Khanewal and Sangla Hill.

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REFERENCES

Ahmad, N. (1933). *I. C. C. C. Tech. Lab. Tech. Bull. (Ser. A) No.* **25**

Ahmad, N. and Gulati, A. N. (1936). *J. Text. Inst.*, T 109

Balls, W. L. (1921) *A method for measuring the length of cotton hairs* : Macmillan and Co. Ltd., London

Barre, H. W. (1938). *Internat. Cotton Bull.* **16**, 64, 521-5

Gulati, A. N. and Ahmad, N. (1935). *I. C. C. C. Tech. Lab. Tech. Bull. (Ser. A) No.* **20**, 6-9

Turner, A. J. (1929). *I. C. C. C. Tech. Lab. Tech. Bull. (Ser. A) No.* **13**

SURVEY OF COTTONS IN BALUCHISTAN

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(With Plates V and VI)

INTRODUCTION

THE survey of the cotton areas in Baluchistan which includes portions, of the Mekran coast in the south and the north Baluchistan contiguous to Sind was financed by the Indian Central Cotton Committee. The tour began in the middle of August and lasted for about nine weeks.

It was found that Kathiawar ports imported *kapas* from the Mekran coast which is partly in Iran and partly in Baluchistan. Any restrictions imposed on the imports of cotton from Iran, to prevent the introduction of new pests and diseases to India, would have to be applied therefore for Baluchistan as well. Information on the Iran cottons had already been collected in a survey of the area undertaken three years previously [Ansari, 1940], and it was suggested that a similar survey of cotton-growing areas in Baluchistan should be carried out in order to collect information on the nature and extent of cotton cultivation in those areas.

MEKRAN

(A) CHARACTERISTICS OF COTTON AREAS VISITED

According to information available, cotton was reported to be grown in the valleys of Dasht, Kech and Kulanch in Mekran, and Nasirabad Tehsil, Sibi, Kachhi Division of Kalat State and Nushki Tehsil in North Baluchistan and the survey was confined to these tracts.

Method of survey

The types of cotton and their morphological characters were noted. Since the identification of the diseases and pests present was an important consideration in the survey, census of the diseased plants was taken by taking 10 random fields in each area and counting the diseased plants in the first 100 in each of the field. Since the number of plants taken formed only about 2 to 3 per cent of the total population in a field, the size of the sample may be considered inadequate, but still it should give an idea of the diseases present. In order to have an idea of the quality of the cotton grown, *kapas* from 10 random plants from each of the fields visited was picked. Small bulk samples of 1 to 2 lb. from the *kapas* picked by the cultivators and left in heaps in the fields were also taken so as to have a larger quantity of material for examination (Plate V). The total number of single plant samples and bulks thus obtained was about 400. Herbarium specimen of diseased plants, specimens of insect-attacked leaves and bolls and also soil samples from each of the fields visited were brought for examination.

Entry into Mekran was made at Gwadar, a port on the Mekran Coast and administered by the Sultan of Muscat. After surveying the valleys of Dasht, Kech and Kulanch the return was made through Pasni. The Kolwa valley was left out since no cotton was reported to be growing there. The whole journey of about 500 miles was done on camels, and the route followed is shown in the map (Plate VI).

Nature of the country and the cotton areas en route

The cultivated area is very scattered. In Dasht area the cultivation is found in and around Garouk and from Suntsar to Kuntdar, and in Kech from Bugdan to Turbat and as far west as Mand. In Kulanch, the areas comprising Nokbur, Zahreen-Kahur and Sardasht are extensively cultivated. It is difficult to give an idea of the acreage under cotton. The lands have not been measured and, besides, cotton is sown as a mixed crop along with *jowar* (*Andropogon sorghum*) and pulses. All that can be said is that the total cultivated area would be about 170 sq. miles, i.e. about 1,08,800 acres, 48 per cent of which would be in Dasht, 34 per cent in Kech and 18 per cent in Kulanch.

The important soils met with in Mekran can broadly be classified into the following :

Milk is a soft and white clay. Having been brought down from the hills and deposited by the streams and hill torrents, it is reputed for its fertility. It is friable, can absorb water quickly and is known to retain moisture for a longer time than the other kinds of soil occurring in Mekran.

Gach is a bluish white clay. Unlike *milk*, it is said to become hard and uncultivable after two or three years, and therefore is left fallow for some period to regain its good properties. It seems to be well adapted for cotton as the plants in *gach* soil appeared to be more luxuriant than in any other soil.

Mat is a silt. Although liable to crack, it is considered to be superior to *milk*. Lands which have received deposits of *mat* once or twice are known as *bug*.

Rek or *zawar* is considered inferior to *milk* only as it takes moisture easily and the sub-soil retains it well. It is extremely well fitted for rice.

Dalo is fragmentary and is composed of rubble and *milk*. It is found in fields excavated in hill-sides along the beds of rivers.

Pat is a hard and white clay. It is compact and does not allow moisture to go deep into it.

Dasht has *milk* and *gach* types, Kech, *rek* and *dalo* types while Kulanch, *milk*, *rek* and *pat* types of soil.

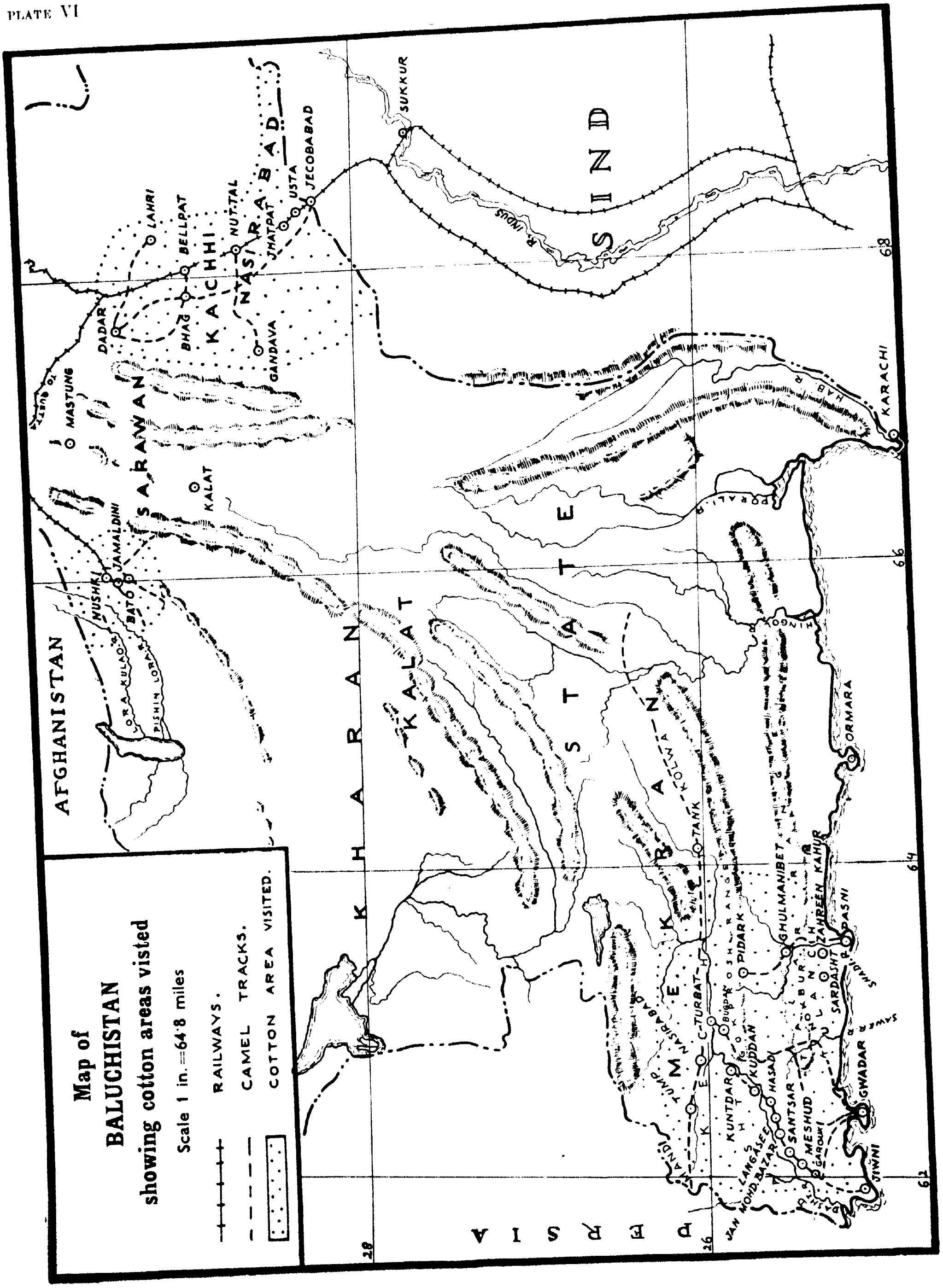
Climate and rainfall

The climatic conditions of Dasht and the Kulanch valley are almost the same. For the greater part of the year the climate is hot and oppressive.

FIG 1. Picking single plants in a field at Kuddan (Dasht, Mekran)

FIG. 2. Taking bulk samples from a heap amassed by the owner of the field (Dasht, Mekran)

PLATE VI



Map of BALUCHISTAN showing cotton areas visted

Scale 1 in. = 64·8 miles

Kech is the hottest of all the three tracts, temperature during July going as high as 113°F. All along the journey in Kech the scorching north wind locally known as *gorich* was experienced. Between November and January, however, the climate is cool and pleasant all over. The rainfall is uncertain and capricious and the country is liable to long periods of drought. In summer it rains between May and September and in winter between February and March. Summer rains are more important, and drought in summer cannot be compensated for by copious rains in winter. The average of temperature and rainfall at Pasni from 1934 to 1937, as calculated from the data obtained from the Locust Research Assistant, Pasni, is given below :

	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Aver.
Temperature	61·2	66·6	71·1	77·2	82·0	85·3	84·6	81·7	79·0	77·4	72·3	67·1	75·5
	±44·6	±43·6	±44·2	±44·2	±42·4	±40·1	±37·2	±37·6	±39·2	±43·5	±45·1	±43·0	±42·1
Rainfall (inches) :	2·035	1·385	0·250	0·115	0·125	nil	0·052	nil	0·005	0·017	0·015	0·797	0·399

Crops

The important autumn crops in Dasht and Kulanch are cotton, *jowar sohro* (an inferior kind of *jowar* with red grains), *mung* (*Phaseolus radiatus*) and *arzan* (*Panicum miliaceum*), while the spring crops are wheat and barley. In Kech, however, cotton is a minor crop and greater attention is paid to the cultivation of rice and *jowar*. Date forms a very important crop in Kech and Kulanch villages. *Jowar* straw and lucerne are the chief fodder.

Type of cotton

The type of cotton met with all along Mekran is *G. herbaceum* var. *typicum* [Hutchinson and Ghose, 1937]. There is a great variation in the size of the bolls and the number of loculi per boll on the same plant. The plants were mostly shrubby, 4-8 ft. high ; habit mainly sympodial with three to five strong vegetative branches. Stems strongly pigmented (grades 1 and 2 [Hutchinson, and Ramiah, 1938]). Stems, petioles and pedicels sparsely hairy. Leaves leathery, usually flat with divergent lobes and open sinuses. Red spot, nectaries on main nerves. Bracteoles broadly triangular, broader than long, slightly to strongly cordate, margins divided into six to eight broadly triangular teeth. Flowers yellow with a deep red spot at the base. Bolls 1 in. to 1¼ in. long, rounded, beaked, surface shallowly dented, green and opening widely when ripe (grade 1 [Hutchinson and Ramiah, 1938]). Lint white or grey. Seeds small, fuzz uniformly distributed over the seed (grades 5 to 7 [Hutchinson and Ramiah, 1938]). In Ketch, the plants also vary in colour from dark green to pale green and in Ootjoo (Tump area), there was found to be an isolated patch of dark green plants which were clearly distinguishable in colour from the pale green ones of the neighbouring fields. There is no other morphological difference between them. In halo-length and ginning percentage the pale greens are found superior to dark greens. I was told that these two kinds of plants usually occur intermixed. The pale greens are known locally as *zard-i-pusht* and the dark greens as ***siah-i-pusht***. In Kech, the crop is late and only about 60 gm. of *kapas* from each of the pale greens and dark greens could be obtained.

(B) AGRICULTURAL CONDITIONS AND PESTS AND DISEASES

Under normal conditions cottons are sown between February and March. but due to uncertainty of rains this period is not rigidly followed. Wheneve, there are rains whether in summer or winter, cotton seeds are dibbled. Ir Kech, it is sown for the sake of rotation only or if some land is left over aften sowing rice and *jowar*. In irrigation also, first attention is given to rice anr, *jowar*. It is therefore usually sown a fortnight or a month later than in Dashtd i.e. in April or May.

Excepting in Kech, where cotton may be seen as a pure crop, it is sown all over Mekran as a mixed crop, usually with rows of *jowar*, ***sohro***, ***mung*** or ***mash*** in between. Three to ten cotton seeds are dibbled at each point by hand, in furrows, distance between the holes and that between the rows of cotton varying from 5 to 10 ft. *Jowar* and pulses are sown by a funnel-shaped ***nai*** made of date palm leaves and attached to the handle of a single-shared plough.

Excepting in Kech, where *karezes* provide permanent source of irrigation, cottons all over Mekran depend entirely on rain-water or flood irrigation. It is allowed to stay in the field even up to six years. In years of no rainfall, however, there is no alternative than to ratoon the crop. Due to the more luxuriant growths of *sohro*, the growth of the cotton plant is retarded in the beginning. At the time of the *sohro* harvest, it is hardly about 2 ft. high After the *sohro* harvest, it grows faster.

Flowering and picking

The period of flowering varies from May to June and the boll formation takes place 10-15 days after flowering. The priod of picking lasts from the end of July till October.

Yield

The lands in Mekran have not been measured and, therefore, no records are available regarding the yield of *kapas* per acre. Usually four pickings are done in each season and from what I observed can say that with a seed rate of only 2 to 3 lb. per acre, the yield of *kapas* varies from 150 to 400 lb.per season. I was told that in the first year the yield is small but lint is of the best quality, locally known as *nihali kapas*. In the second and third years the yield is the highest. The month of September gives the largest yield. Dasht area yields about 56 per cent of the *kapas* produced in Mekran, Kech 10 per cent and Kulanch 34 per cent.

Pests and diseases

The pests and diseases common in Mekran were the pink bollworm, spotted bollworm, dusky cotton bug, white-fly, plant lice and stenosis. They have since been confirmed by the reports received from the Imperial Mycologist and the Imperial Entomologist, Delhi, to whom specimens of diseased bolls and plants were sent for identification. Out of the three valleys visited Kulanch suffered heavily. The statistical examination of the diseased plants (cf. Method of survey, above) showed that while there were no significant differences in the incidence of diseases from field to field, there were sharp differences in the intensity of the different diseases. Out of a total of 31·5 per cent of the diseased plants those suffering from stenosis alone amounted to 14·5 per cent. The remaining 17 per cent suffered from bollworms and white fly. In Dasht and Kech, pink bollworm, white-fly and dusky cotton bug are found on cotton plants, but the damage done was negligible.

In Tump (Kech area), I was informed by the local Revenue Officer that in certain seasons there the cottons suffer from a particular disease known as *sheergoo* so-called because a sort of sweet sticky substance, *shira*, is found on the plant body. Inside the *shira* are to be found insects round and green in colour. The plants suffer at any stage of their growth but usually at maturity, with the result that they gradually turn black and die. I did not see the disease but, from what I am informed, it may be probably due to plant lice.

(C) PRODUCTION OF COTTON

Only a negligible amount of cotton produced in Indian Mekran is used inside the country for making quilts and fish nets. Due to the import of cheap cloth from foreign markets, home-made cloth is practically non-existent. The khaki cotton industry, the cloth of which is very much liked by the people, has almost died out. Preparation of rugs and *dari* stitching has practically ceased to exist.

There are no ginning factories in Mekran. The merchants at Gawadar and Pasni lend money to the cultivators and get *kapas* from them in return at the rate of Rs. 2-8 to Rs. 8 per maund. The ginning out-turn is about 28 per cent. These cottons, after ginning in Kathiawar, fetch Rs. 18 to Rs. 40 per maund. Before the prohibition of the import of unginned cottons to Kathiawar ports was passed, almost the whole of the *kapas* produced in Indian and Iranian Mekran used to be sent to Cutch and Kathiawar. The enforcement of the prohibition has had a marked check on the export of cottons from these parts to India. I could see over 4,000 mds. of *kapas* in Gawadar and about the same quantity in Pasni lying in stock with the cotton merchants for the last two years. It is difficult to give an exact figure for the total amount of *kapas* produced in Mekran and that exported. The lands had not been measured and records for the total produce of the country were not kept. Kalat State appraises one-tenth of the total produce of *kapas* as revenue, and the figures which are available for the last 10 years are given in Table I.

Ten times of the above figures would give an idea of the produce on which revenue is charged, while there were about 40 per cent of the lands which, being *muafiyat*, were exempted from revenue and for the produce of which, therefore, no records were available.

It will be seen from Table I that the year-to-year figures exhibit great variation. After excluding the years 1932-33 and 1933-34, which give exceptionally low and high yields respectively, the average per year would be

4,300 mds. If 40 per cent of the exempted *kapas* is added to the above, the average per year will increase to 7,166 mds.

TABLE I

One-tenth of the produce appraised as revenue in mds.

Year	Areas			
	Dasht	Kech	Kulanch	Total
1928-29	201	13	129	312
1929-30	113	4	95	212
1930-31	93	25	221	339
1931-32	61	12	227	300
1932-33	41	45	41	127
1933-34	549	56	388	993
1934-35	344	10	24	378
1935-36	495	106	94	695
1936-37	368	93	299	760
1937-38	282	90	42	414
	2,547 56 per cent	454 10 per cent	1,560 34 per cent	4,560 100 per cent

The figures for the export of *kapas* from Pasni to India from 1935-36 to 1937-38 as supplied by the Port Officer, Pasni, are given below :

Year	Quantity of *kapas* exported in mds.
1935-36 . . .	9,120
1936-37 . . .	13,682
1937-38 . . .	4,749
Total . .	27,551

It will be seen that the average annual export is 9,183 mds. The figures for the export of *kapas* and the total produce of the country thus agree fairly closely.

Seth Bande Ali, the biggest cotton merchant at Gawadar, informed me that the yearly export of *kapas* from Indian and Iranian Mekran combined varied from 21,625 to 33,935 mds. According to him, 56 per cent of this quantity is exported from Chabbahar Iranian 'Mekran and the remaining 46 per cent from Indian Mekran which comes to be 9,947 to 15,610 mds.

The soil of Mekran, particularly that of Dasht and Kulanch, is extremely well fitted for cotton. Without any manuring and agricultural operations after sowing the crop, yields between 150 to 400 lb. of *kapas* are obtained per season. Although Kulanch cottons at the time of my visit were suffering from diseases, the fact that there are immense possibilities of improving the cottons in Mekran needs no emphasis.

NORTH BALUCHISTAN

Soil

The soil all over the areas visited in North Baluchistan is chiefly alluvial and very fertile wherever water is available. The best is light loam mixed with a proportion of sand and is locally known as *mat*. It requires less water, retains moisture longer and is suited for all crops. The other kind is *khauri* or *reti* which, having more of sand, is very suitable for *jowar*. In Nushki particularly, a hard stony soil known as *daddo* and *sov* impregnated with salt are also found. Both of these are of inferior type.

Climate and rainfall

The climatic conditions of Nasirabad and Kachhi are very nearly the same. Rainfall is scanty, varying between 3 to 5 in. There are only two marked seasons, summer and winter, the former beginning from April and the latter from October. The temperature during April and October is very variable. In December and January—the coldest months—the temperature goes down to 27°F. The hottest months are June and July when at times the deadly *simoom* prevails. Kachhi is regarded as one of the hottest tracts in India.

In Nushki, there are four marked seasons, *hatam* or spring, from March to May, *tirma* or *bashasham*, i.e. the rainy season, between June and August, *sohel* or autumn, comprising September and October and *selt* or winter.

The average temperature for different seasons from September 1936 to September 1938 and the average yearly rainfall from 1928 to 1938 as calculated from the figures obtained from the Agency Office, Nushki, are given below :

Seasons	Average temp. (°F.)	Rainfall average per year (in.)
Spring	78·7 ± 11·9	0·616
Rainy season	96·5 ± 11·9	
Autumn	88·3 ± 6·1	
Winter	57·4 ± 7·7	

Type of cotton

In Nasirabad and Nushki, cotton has been introduced recently and is of the Punjab-American type obtained from Sind. The British Cotton Growing Association and the Agricultural Department, Baluchistan, both have their stations in Usta Colony, Nasirabad. They are trying KT-23, KT-25, 43F 4F, 4F-98 and 45F (all Punjab-Americans) and N T 12 (Sind Desi) obtained from Sind. In Gandawa and Lehri out of a total of about 250 acres under cotton, only about 70 acres were under *herbaceums*, while the remaining were under Punjab-Americans. Sibi was all under Punjab-Americans.

Agricultural conditions of the cotton crop

The agricultural conditions in Nasirabad are like those of Sind. The tract enjoys the beneficence of the Kirthar branch of Sukkur barrage. In Kachhi, Sibi and Nushki, cotton cultivation depends on flood irrigation by rivers or permanent irrigation provided by *karezes*. In Kachhi and Sibi the floods generally occur in July and August and sometimes during the spring also. If floods occur in spring, i.e. March, cotton seed locally known as *kakri* is broadcast immediately after *jowar*. Sometimes *jowar*, melons and cottons are all broadcast. In Nushki, the sowing time is from February to March and picking is done between October and November. In 1936-37, there was a bumper crop and, due to scarcity of labour, half of the *kapas* was left unpicked. In 1937-38, fearing a waste of *kapas* again only about 100 acres were sown with cotton. The *herbaceums* found in this tract differed from the Mekran *herbaceums* in the following characters only : Stems green (grades 4 and 5 [Hutchinson and Ramiah, 1938]). Leaves with open or slightly rumpled sinuses. Bracteoles rounded, strongly cordate. Bolls opening moderately widely when ripe (grade 2 [Hutchinson and Ramiah, 1938]).

Pests and diseases of cotton

Herbaceums in North Baluchistan were practically free from diseases and pests. In Nushki, the Punjab-Americans suffered from bollworms and red-leaf to the extent of 1 to 2 per cent only. In Nasirabad and Gandawa the pests on Punjab-Americans were bollworms, plant lice and white ants and the incidence of disease was 21 per cent and 30 per cent respectively. The data obtained by the census of the diseased plants were statistically examined and it was found that, while difference in the incidence of disease from field to field was not significant at any one of the two localities, there were sharp differences in the intensity of various diseases, and the spotted bollworms and plant lice took significantly the heaviest toll at both these places. In Hazarwah (Nasirabad), several of the plots of Punjab-Americans sown by the British Cotton Growing Association were completely destroyed by root-rot fungus. Cottons sown late, i.e. in June, were liable to attack by the black-headed cricket. Several plots in Nasirabad and Kachhi were destroyed by this pest. Some damage was also done by heavy bud and boll shedding.

Cotton production

There is no regular cotton industry in North Baluchistan and therefore almost all that is produced is sold to the local *bania* who carries it to Sind.

As regards the acreage and the total produce of cotton in the areas surveyed there were no records available excepting the records kept by the British Cotton Growing Association for their own cottons in Usta. My own estimate of the total land under cotton for 1937-38 is 3,400 acres arrived at as follows :—

	2,500	acres	under the British Cotton Growing Association in Usta Colony
	550	,,	round about Sibi
	200	,,	in Gandawa
	50	,,	in Dadhar
	100	,,	in Nushki
Total	3,400	acres	

Out of these 3,400 acres, about 70 acres (in Gandawa and Dadhar only) were under *herbaceums*, while the remaining 3,330 acres were under the introduced Punjab-American cottons. The total produce of *kapas* from these 3,400 acres (at an average of 200 lb. per acre) will be about 8,500 mds.

There are no ginning factories in Baluchistan and therefore the *kapas* is sent to Jacobabad, Shadadkot, Sukkur, Dharki and Reti in Sind. Bhawalpur State *kapas* also goes to these places. The British Cotton Growing Association have their own ginning factories at Reti. Cottons when grown in Jhalawan or Las Bela find their way to Dadu and Karachi respectively. There are great possibilities of growing cottons in the Kachhi Division of Kalat State, Sibi district and Nushki. Kalat State has already taken a lead in the matter and established an agricultural farm at Gandawa, where cottons from Sind are being tried. Round about Sibi, Mr Ata Mohammad, a local zamindar, has devoted a considerable part of his lands to cotton. There is a handicap due to the scarcity of water, but some improvements in water supply are already in progress. Nasirabad sub-division already enjoys the benefit of the Kirthar branch of the Sukkur Barrage and has irrigation available all the year round. In areas like Sibi, Dadhar, Gandawa and Nushki, there are a number of *karezes* and some more are being provided. The soil is alluvial and seems to be particularly well fitted for cotton wherever irrigation is available.

In Nasirabad I was informed that cultivators are lazy and do not want to work for cotton which requires more care and work than other crops. I think the trouble is due more to the reduced share they get in the *batai* (i.e. share in the produce of the crop). If they are given half of the produce as in the Punjab, instead of one-third as they are getting in Nasirabad, probably they would feel more encouraged to take to cotton. Another handicap, in my opinion, is that cultivators do not know from where to get the seed. The British Cotton Growing Association's activities are confined to Nasirabad only. In other places the difficulty can be obviated by the tehsildars or maustaufees who can easily make arrangements for the supply. A further impetus to cotton-growing can be given by awarding prizes in the local exhibitions and fairs which are frequently held.

QUALITY OF COTTON

Mekran

The single plant samples and bulks brought were examined for maximum halo-length by Bailey's protractor and for ginning percentage. For halo-length five seeds per plant and 50 seeds for each bulk were examined. The results are tabulated on the next page.

Herbaceum		Single plants					Bulks				
Locality		Lint length in mm.			Ginning percentage		Lint length			Ginning percentage	
		No. of plants	Range	Average	Range	Average	No. of Bulks	Range	Average	Range	Average
Dasht area	Meshud	20	21-28	24·1	21-34	26·6	*	*	*	*	*
	Suntsar	4	22-26	24·3	23-27	25·2	*	*	*	*	*
	Jan Mohd. Bazar	40	21-29	24·8	18-33	26·3	8	23-26	24·6	22-32	24·7
	Zareen Bagh	10	20-29	24·9	21-29	23·4	2	24-27	25·5	21-29	24·9
	Langasee	21	23-30	26·7	19-30	26·3	2	24-25	24·5	23-26	24·6
	Hasadi	9	23-27	25·5	17-40	29·5	2	26-27	26·5	22-29	25·6
	Kuddan	18	20-32	26·5	18-32	22·2	5	27-28	27·8	25-28	25·7
	Total	122	20-32	25·3	18-33	25·7	19	23-28	25·8	21-32	25·1
Kulanch area	Nokbur	69	20-30	24·7	22-42	31·3	7	24-26	25·3	26-35	29·5
	Sardasht	20	22-29	25·7	26-41	33·2	3	25-26	25·4	28-31	30·1
	Zahreen Kahur	20	21-29	24·9	21-39	31·5	4	23-25	24·6	28-39	31·6
	Total	109	20-30	24·9	21-42	31·6	14	23-26	25·0	26-39	30·4
Kech area	Nasirabad	*	*	*	*	*	1	27·7	27·7	33·2	33·2
	Tump—Pale green plants	*	*	*	*	*	1	27·5	27·5	27·9	27·9
	Tump—Dark green plants	*	*	*	*	*	1	25·0	25·0	23·5	23·5
	Total for all the areas	231	20-32	25·1	18-42	28·5	36	23-28	25·9	21-39	28·3

The data for halo-length and ginning percentage were statistically examined for differences between the areas of Dasht and Kulanch, within the areas (i.e. between localities of each area), and within localities (i.e. between fields of each locality). The results obtained are the following :

(*1*) *Halo-length.*—(*a*) In halo-length, while there were no significant differences between Dasht and Kulanch areas, the localities Langasee and Kuddan were both significantly superior to Meshud and Jan Mohammad Bazar.

(*b*) In the localities Langasee and Nokbur, fields differed significantly between themselves.

(*2*) *Ginning percentage.*—(*a*) In ginning percentage, the Kulanch area was 6 per cent significantly higher to the Dasht area. As for the localities, Meshud, Jan Mohammad Bazar and Langasee were significantly superior to Kuddan in the Dasht area, and Sardasht to Nokbur in the Kulanch area.

(*b*) In Nokbur, fields differed significantly between themselves.

(*3*) The statistical examination of the halo-length of pale green and dark green *herbaceums* obtained from Tump (Kech) showed that the pale greens had 2·5 mm. significantly longer halo-length than the dark greens.

(*4*) On correlating the averages of halo-lengths and ginning percentages of single plants obtained from 18 different fields in Mekran with the averages of bulks obtained from the same fields it was found that the coefficient of correlation (r) for the halo-length was + 0·4370, and that for ginning percentage + 0·7237 both being significant at $P = 0{\cdot}01$. The lint of the *herbaceums* collected from Mekran was sent for fibre test to the Technological Laboratory, Matunga. The fibre particulars received from there are given below :

1. Mean fibre-length (inch)	
(*a*) By Balls Sorter	0·78
(*b*) By Baer Sorter	0·78
2. Mean fibre-weight per inch (millionth of an ounce)	0·265
3. Maturity test results (per cent)	
(*a*) Mature	79
(*b*) Half mature	12
(*c*) Immature	9

According to the report, the Mekran *herbaceums* have very nearly the same mean fibre-length and mean fibre-weight per inch as Wagad-8 cotton grown in Viramgam and have 79 per cent mature fibres as compared to 47 per cent only in the latter collected this season. It is stated that they belong to a much inferior class of *herbaceums* as compared with those collected by the author from Iran in 1936 [Ansari, 1940]. A comparison of the Mekran *herbaceums* with the above Iranian *herbaceums* and the standard Indian *herbaceums* with regard to season, soil, yield, quality, etc. can be had from the Appendix.

North Baluchistan

The halo-length and ginning percentage for the single plants are given below :

Locality	Type of cotton	Halo-length in mm.			Ginning percentage	
		No. of plants	Range	Average	Range	Average
Khari . . .	*Herbaceum* .	10	22-28	25·7	20-28	23·8
Kot Bachal Shah .	Do. .	13	21-26	24·3	22-37	25·2
From near the Seed Farm, Gandawa .	Do. .	21	19-31	24·7	16-34	26·4
		44	19-31	24·9	16-34	25·5
Nasirabad, Kachhi, Sibi and Nushki .	*Hirsutums* (P-A)	66	20-35	29·7	21-38	30·4

SUMMARY

(1) The cotton-growing areas in Indian Mekran and Kalat State of south and east Baluchistan and of Nushki in north Baluchistan were surveyed. Mekran grows *herbaceum* cottons, while in most parts of north and east Baluchistan, the indigenous *herbaceums* have been replaced recently by the Punjab-Americans introduced from Sind.

(2) Excepting the Kech Valley, where cotton is a minor crop, constituting about 10 per cent of the total production, cotton is sown all over Mekran as a mixed crop with rows of *jowar* and pulses in between. While in Kech there is a permanent source of irrigation, in other portions of Mekran, the crop depends on rain water or flood irrigation and is ratooned for even six years.

(3) A rough survey of the pests and diseases revealed that the severity of incidence did not vary from place to place. Stenosis was the only disease of importance and it amounted to about 14 per cent of the plants. Among insects observed the two bollworms, spotted and pink, were more prominent and white-fly to a smaller extent, the total insect-infected plants amounting to about 17 per cent of the population.

(4) Only a negligible amount of cotton produced in Mekran, is consumed inside the country. There are no ginning factories in Mekran. The merchants in Gawadar and Pasni buy *kapas* from the cultivators and send it to Kathiawar for ginning and sale. The Act prohibiting the import of unginned cottons into Kathiawar ports has resulted in the accumulation of two years' stocks, up to about 8,000 mds.

(5) The estimate of the yearly export of *kapas* from Indian Mekran to Kathiawar and Cutch, as reckoned from the data obtained from different sources, comes to about 10,000 mds.

(6) In North Baluchistan, the agricultural conditions of Nasirabad are more or less like those of Sind. The tract enjoys the beneficence of the Kirthar branch of the Sukkur Barrage. The *herbaceum* here, which now occupies only a very small area, was practically free from diseases and pests. In places where the American cotton has now been grown for some years the crop was found to suffer badly from bollworms and plant lice, the total incidence amounting to 20-30 per cent of the plants. There was also some damage due to root-rot fungus.

(7) About 3,400 acres are reckoned to be under cotton in north Baluchistan. All the *kapas* is sent to Sind for ginning.

The bulk of the samples examined by the Matunga Laboratory was found to have 0·78 in. mean fibre-length and 0·265 mean fibre-weight per in., both very nearly the same as of Wagad-8 grown in Viramgam, and 79 per cent mature fibres as compared to 47 per cent only in the latter collected this season.

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REFERENCES

Ahmad, N. (1939). *I. C. C. C. Tech. Bull. Series A.*, No. **49**

Ansari, M. A. A. (1940). *Ind. J. Agric. Sci.* **10**, 522

Hutchinson, J. B. and Ghose, R. L. M. (1937). *Ind. J. Agric. Sci.* **7**, 233-57

Hutchinson, J. B. and Ramiah, K. and the members of two special sub-committees (1938). *Ind. J. Agric. Sci.* **8**, 567-90

APPENDIX

Comparison of Mekran (Baluchistan) Herbaceums *with Iranian and standard Indian* Herbaceums

(Data for Indian cottons are from Tech. Bull. Series A, No. 49, July 1939)

Type	District of growth	Growing period	Soil	Annual rainfall	Temperature (°F.)	Yield of *kapas* per acre	Ginning percentage	Fibre-length (in.)		Fibre-weight per inch (millionth of an ounce)
								Balls	Baer	
				Mekran *herbaceums*						
Mekran (Baluchistan) *herbaceums*	Valleys of Dasht, Kech and Kulanch	Sown between February and March in Dasht and Kulanch valleys and in April or May in Kech. Picked from the end of July till October	In Dasht valley, clayey, soft and white. In Kech sandy clay and grey. In Kulanch either clayey like that of Dasht or sandy clay like that of Kech	At Pasni, the average = 0·399 inches	At Pasni, the average = 75·5 ± 42·1	150 to 400 lb. per acre	Average = 28·3 Range from 21 to 39	0·78	0·78	0·265
				Iranian *herbaceums*						
Iranian *herbaceums*	Siestan, Khorasan, Guilan and areas of Qom Kashan, Isfahan and Faras	Sown all over Iran from March to May except in South Iran, where it is earlier, the first 3 weeks of February. Picking from July to October	Predominantly light loam. The exceptions are the heavy soil areas of Tehran to Morchikhat and Isfahan	In Siestan and East Khorasan about 4 in. In Western Khorasan about 9 in. In Tehran and roundabout 5 in. In Isfahan about 5 in. and in Bushire about 13 in. The number of irrigations varies from 4 to 6 depending upon the availability of water	At Mashhad (Khorasan) mean = 56·3 and range from 15 to 76. At Tehran, mean = 60·4 and range from 30 to 111. At Isfahan mean = 58·0 and range = −3 to 106. At Shiraz mean = 65·0 and range = 21 to 113. At Bushire average = 75·4 and range = 91 to 109	400 to 600 lb.	33 per cent in East Iran, 40 per cent in Guilan area and 33 per cent in Isfahan area	0·90	0·94	0·195

Indian *herbaceums*

Jayawant	**Dharwar, Belgam, Bijapur, etc.**	Sown from the first week of August to the end of September and usually picked from the second week of February up to middle of April	Deep and medium black soil	20 in. to 30 in.; 27·67 in. in 1938-39	Average minimum about 60	Normally about 300 lb.	26—29	0·88; 0·89 in 1938-39	0·197 in 1938-39
Surat 1027 ALF	**Broach tract** .	Sown from third week of June and picked from the last week of February onwards	Black cotton soil	30 in. to 40 in.; 36·9 in. in 1938-39	Mean 85 from April to August. Mean 81 from September to November. Max. 110; Min. 55	553 lb. in 1938-1939	37·5	0·93; 0·93 in 1938-39	0·197 in 1938-39
Wagad-8 .	**North Gujrat-Viramgam, N.-W. Kathiawar and Cutch**	Sown in the beginning of July and picked in March	*Besar*, a saltish alluvium	13 in. to 30 in.; 14·57 in. in 1938-39	Mean 110, minimum 52, lowest monthly average =59·7 (December)	518 lb. in 1938-1939	38 in 1938-39	0·80; 0·80 in 1938-39	0·270 in 1938-39
Hagari .	**Bellary district and also in parts of Raichur district in Hyderabad**	Sown from the last week in August to the end of September and picked from about the first week of February to the end of March	Black cotton soil	Normally 20 in.; 22·09 in. in 1938-39	Mean minimum = 63·2, range 44·5 to 76·0, mean maximum 89·7, range 78·7 to 102·8	Normally 250 lb.; 490 in 1938-39	28	0·89; 0·90 in 1938-39	0·192 in 1938-39

THE TIME OF DIFFERENTIATION OF THE FLOWER-BUD OF THE MANGO

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(With Plates VII and VIII)

INTRODUCTION

IN a study of alternate bearing in the mango [Sen, 1938, 1939 ; Lal Singh and Khan, 1939] it seemed important to determine the time of flower-bud formation, firstly to elucidate the factors governing their formation, and secondly to determine the time at which cultural treatments aimed at controlling flower-bud formation should be applied to give the desired effect at the critical time of bud differentiation.

In the case of deciduous fruits, such as the apple, pear, plum, cherry, etc. it has been determined that the flower-buds are formed during the summer preceding the spring in which they open. The time of flower-bud differentiation coincides with the time at which elongation growth tends to cease ; the weather is rather dry and hot and the concentration of carbohydrates in the tissue increases rapidly [Chandler, 1925]. Flower-bud formation may be inhibited or favoured by cultural treatments, such as manuring, pruning, thinning, etc. given to bear the desired effect upon shoot growth and the carbohydrate-nitrogen ratio.

The mango is evergreen and in this case shoots are found to grow in more than one flush, the earliest being about the beginning of March (under Sabour conditions). These growths usually break out of terminal buds on previous year's shoots that fail to flower. Subsequent flushes appear as laterals in April or beginning of May on previous year's shoots that flower but fail to set fruit. In July-August laterals may appear on bearing shoots after harvesting. There is often yet another flush of growths appearing still later in the year—as late as September-October. These generally arise from the weak growths of the previous year that usually fail to produce any growth, vegetative or reproductive, earlier in the season. After they have had some time to mature themselves and accumulate sufficient reserves, they may throw new growths towards the end of the season. Besides, some secondaries on current year's primary shoots are also found to appear during this period. It has been found that the early shoots that cease elongation growth about the end of June are the ones most likely to flower in the following season. Those yet growing as late as September-October seldom flower [Sen, 1939]. Generally the March shoots and some of the early laterals are most likely to flower in the following year.

Although the mango is evergreen, there occurs a complete cessation of growth for a short period from the middle of November to the middle of December. Immediately the growth is resumed the flower-buds become apparent by their swelling. It would, therefore, appear that bud differentiation must take place sometime between this time and the preceding June, i.e. the time at which the category of shoots most prone to form flower-buds tend to cease length growth. It is intended in the study described below to determine the time of flower-bud differentiation more precisely.

MATERIAL AND METHOD

Three trees of 15-year old Langra mangoes, in one of the experimental orchards (New Orchard) at Sabour, were selected for this study in 1937. The trees were in good health but had already shown the habit of alternate bearing. In 1937 and 1939 they were in their ' off ' year while in 1938 they were in their ' on ' year. The orchard received no treatment except three to four ploughings a year. March shoots were labelled during the last week of May, when they were yet easily recognizable. The shoots were selected at random all over the tree; 200-250 shoots per tree were taken. Samples of terminal buds from the labelled shoots were collected at regular intervals from June to the following January to study their microtome sections. From June to September samples were taken every fortnight. Later on, from October to January weekly samples were collected. Each sample consisted of three or four terminal buds taken from the labelled shoots on a tree making a total of 10 buds collected from the three trees.

The work was repeated in 1938 and 1939. In these years two more trees were used for the supply of the material, as it was feared that the three trees originally selected in 1937 might be adversely affected if so many buds were removed from them year after year. In 1938 material was collected beginning from 25 July and in 1939 from 1 September. In 1938 samples were taken every fortnight from 25 July to the 16th of the following January. In 1939, it was decided to take weekly samples from 1 September till the middle of the following January.

In each case care was taken to collect buds distributed all over the trees. The buds were removed close to the base by a clear cut with a sharp knife and placed immediately in formalin-alcohol, and were then removed to the laboratory where they were evacuated under an exhaust pump (Geric). The material was then washed and dehydrated through the alcohols following the usual technique. When the buds were in 70 per cent alcohol they were cut off from the woody base and the outer hard scale leaves were removed [Gibbs and Swarbrick, 1930]. The buds were then passed through the alcohol and xylol series as usual till they reached pure xylol for clarification. They were then embedded in paraffin of melting point 48°–52°C. Radial longitudinal sections were cut and stained in Haidenhain's iron-alum hæmatoxylin.

A flowering shoot of mango is quite familiar. It consists of primary, secondary and tertiary floral branches. The rachis and the primary and secondary branches are racemes while the ultimate branches are dichasia. The inflorescence is known as panicle. The mean size of the buds before they begin to swell in December is 1·0 cm. × 0·7 cm., whereas a normal panicle of Langra is easily about 20 cm. in length and 15 cm. spread at the bottom. During the month of January when the flower heads are very rapidly developing but yet only about 2-3 cm. in length, one easily notices the primary branches, known as panicula, emerging in the axils of the bud scales which themselves also grow in size. Between this time and the latter part of February, the panicles develop rapidly to full bloom. For the purpose of determining whether a bud is differentiating into a flower-bud or not, the earliest indication was considered to be the occurrence of rudiments of the primary floral branches in the buds. For actual microscopical examination the criterion employed was the occurrence of protrusions in the axils of the bud scales. In the first year it was advantageous to begin the microtomical work with the material collected after bud swelling in December and proceed retrogressively examining the earlier samples. The microphotographs of sections of buds in Plates VII and VIII show the phenomenon very clearly.

RESULTS

The data for 1937, 1938 and 1939 are presented in Tables I, II and III respectively.

In the two poor bearing years of 1937 and 1939, differentiation was first definitely noticed in the beginning of October. In 1938, when the trees had borne a heavy crop, differentiation was delayed by about a fortnight, but in none of the years could any trace of bud differentiation be detected in any of the samples collected before the end of September. Although the shoots ceased growth as early as June or July, flower-bud differentiation did not take place before the month of October. It would, therefore, seem probable that the advent of cold and dry conditions bringing a sharp change in the climate in October is closely related to flower-bud differentiation of the mango.

Further, it is shown, especially in 1937 and 1939, when flower-bud formation was particularly favoured, that the number of buds differentiating into flower-buds increase steadily from the beginning of October to the middle of November. This suggests that flower-bud differentiation is active during the whole of this period, i.e. about six weeks immediately preceding the time of cessation of growth from the middle of November to the middle of December.

The short delay in the initiation of bud differentiation in 1938 would seem reasonable because this year the tree having produced a heavy crop was liable to run into exhaustion. The carbohydrate-nitrogen ratio* was probably less favourable so that although necessary seasonal change might have appeared by the end of September, the other factors did not become favourable till a few days later. In this case, as will appear from Table II, even after October, only a small percentage of the sampled buds were found to differentiate flower-buds, as compared with those in the case of 1937 and 1939. Incidentally, two extra samples were taken on the 2nd and 16th January,

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* A high carbohydrate-nitrogen ratio favours flower-bud formation [Chandler, 1925]

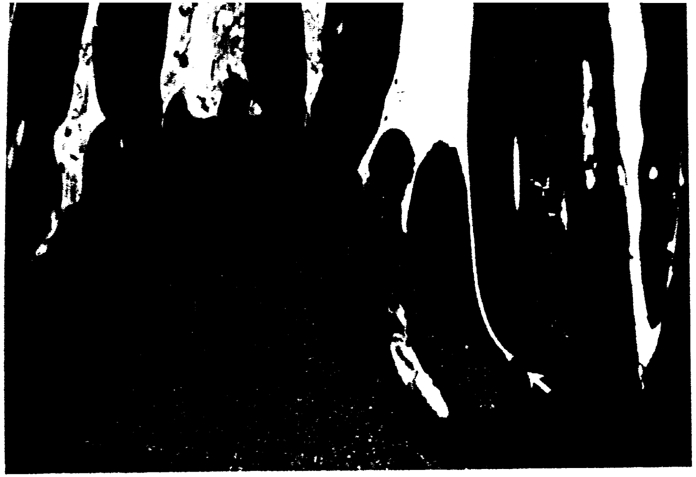


Fig. 1

Primary floral branch primordia (×40) (first sign of flower-bud differentiation seen as small protrusion in the axil of bud-scale indicated by white arrow-head)

October 10, 1938

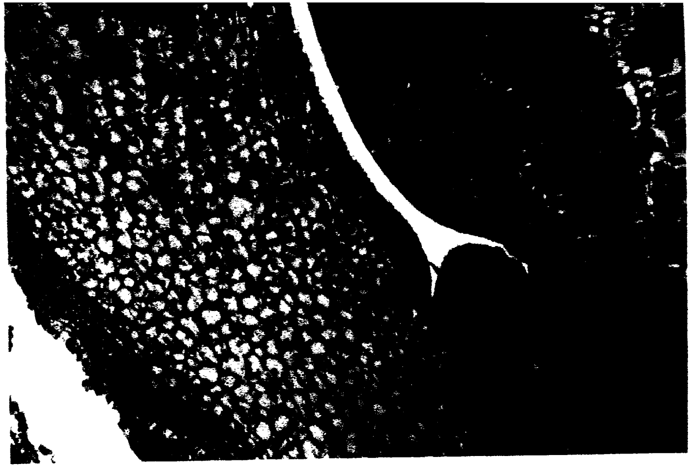
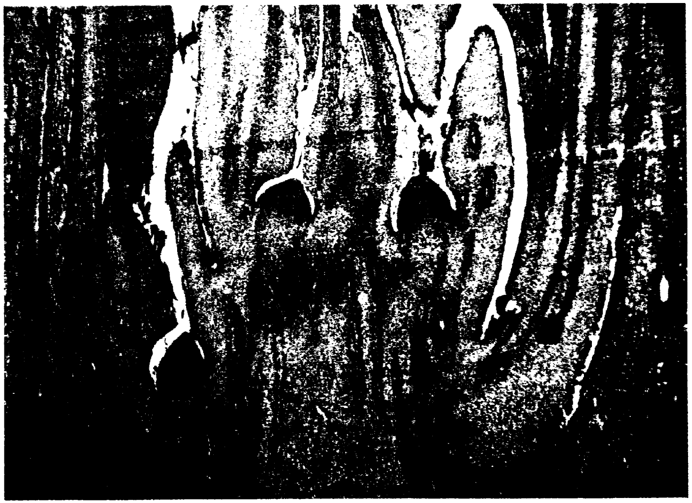
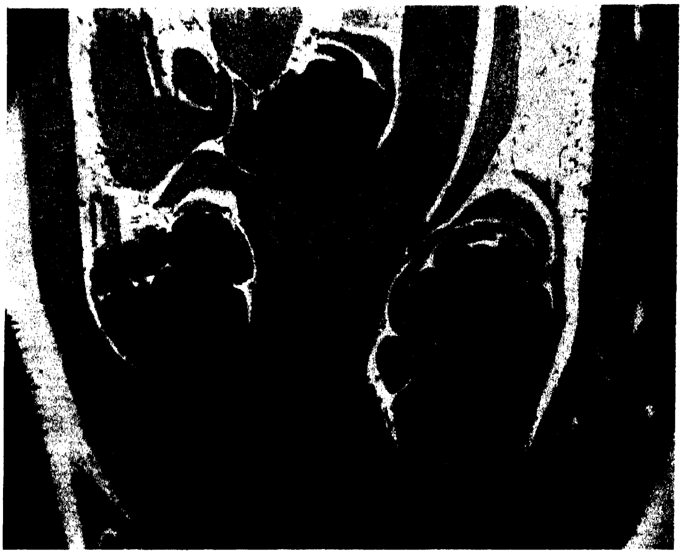


Fig. 2

Site of protrusion more highly magnified (× 180) to bring out the differentiation of the primordia seen in Fig. 1

October 10, 1938





1. Flower-bud at a still more advanced stage showing the panicula being differentiated (×40)
January 20, 1940

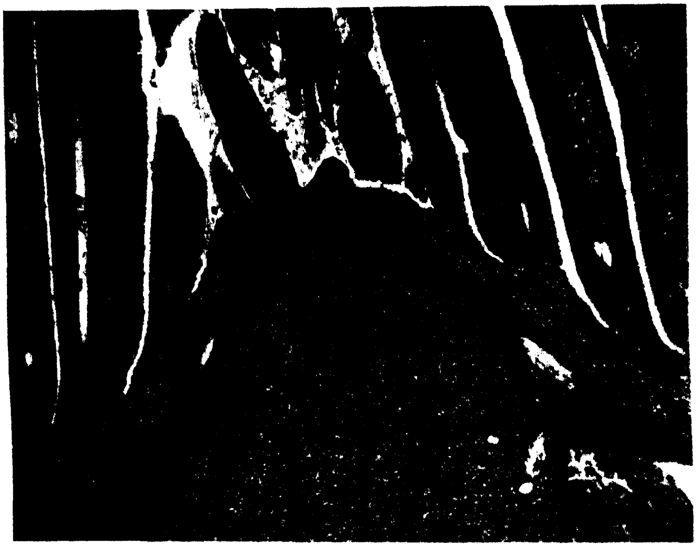


FIG. 2. Vegetative bud without any protrusion in the axils of bud scales (×40)
January 2, 1939

1939, i.e. during the season in continuation of that of 1938, consisting of buds looking relatively fatter. Only these two samples included a fairly high percentage of flower-buds, indicating that flower-buds may be fairly accurately recognized by their characteristic size even before they break.

TABLE I

Time of flower-bud differentiation in mango (Langra), 1937

Serial No.	Date	No. of buds collected	No. * of buds examined	Thickness of section in microns	No. differentiated into flower-bud
1	June 1 . .	10	10	10	*Nil*
2	June 16 . .	10	10	10	*Nil*
3	July 1 . .	10	10	10	*Nil*
4	July 16 . .	10	10	8—10	*Nil*
5	August 1 . .	10	10	8—10	*Nil*
6	August 16 . .	10	10	10	*Nil*
7	September 1 .	10	10	10—15	*Nil*
8	September 16 .	10	10	10—15	*Nil*
9	September 30 .	10	10	10—15	*Nil* †
10	October 7 . .	10	10	10	3
11	October 14 .	10	10	10	4
12	October 21 .	10	10	10—15	6
13	October 28 .	15‡	12	10	5
14	November 4 .	10	10	10	8
15	November 11 .	10	10	10	9
16	November 18 .	10	8	10—15	7
17	November 25 .	10	10	25	8
18	December 2 .	10	10	20	8
19	December 9 .	10	10	20	10
20	December 16 .	10	10	15	9
21	December 23 .	10	..	..	..
22	December 30 .	10	10	15	9

* Some buds were spoiled during operation

† Doubtful in two cases

‡ Just by chance, 5 buds each were collected from the three trees on this date

TABLE II

Time of flower-bud differentiation in mango (Langra), 1938

Serial No.	Date	No. of buds collected	No. * of buds examined	Thickness of section in microns	No. differentiated into flower-bud
1	July 25 . .	10	10	8—10	*Nil*
2	August 8 . .	10	10	8—10	*Nil*
3	August 22 . .	10	10	8—10	*Nil*
4	September 5 .	10	10	10	*Nil*
5	September 19 .	10	10	10	*Nil*
6	September 26 .	10	8	8—10	*Nil*
7	October 10 .	10	9	15	*Nil* †
8	October 24 .	10	10	12	2
9	November 7 .	10	10	10	1
10	November 21 .	10	10	15	2
11	December 5 .	10	10	14	1
12	December 19 .	10	10	12—14	2
13	January 2, 1939	10	10	10—12	1
14	January 2, 1939 .	10 (fat buds)	10	12	8
15	January 16, 1939	10	10	10	2
16	January 16, 1939	10 (fat buds)	10	14—16	7

* Some buds were spoiled during operation

† Doubtful in two cases

TABLE III

Time of flower-bud differentiation in mango (Langra), 1939

Serial No.	Date	No. of buds collected	No. of buds examined	Thickness of section in microns	No. differentiated into flower-bud
1	September 1 .	10	10	8—10	*Nil*
2	September 8 .	10	10	10	*Nil*
3	September 15 .	10	10	12	*Nil*
4	September 22 .	10	10	8	*Nil* *
5	September 29 .	10	10	14	*Nil* *
6	October 7 . .	10	10	10—12	2
7	October 14 .	10	10	12	3
8	October 21 .	10	10	10	5
9	October 28 .	10	10	10	4
10	November 4 .	10	10	10	4
11	November 11 .	10	10	12	7
12	November 18 .	10	10	10	8
13	November 25 .	10	10	8	6
14	December 2 .	10	10	10—12	8
15	December 9 .	10	10	12	9
16	December 16 .	10	10	12—14	8
17	December 23 .	10	10	14	9
18	December 30 .	10	10	14	10
19	January 6, 1940	10	10	14	9
20	January 13, 1940	10	10	14	10

* Doubtful in one case

It is found that in the case of mango, the shoots that flower in the following year make most of the extension growth early in the season and cease growing about a month earlier as compared to the shoots that do not flower in the following year [Singh and Khan, 1940]. Again from the data presented here, it is shown that although a shoot may cease growing as early as June-July, it does not initiate bud differentiation before October. It would, therefore, seem that in the case of the mango there must pass an interval between the time of cessation of elongation growth and that of bud differentiation. It is probable that the shoot matures and accumulates appropriate reserves during this interval.

The critical time of bud differentiation occurring immediately before the time of cessation of growth, between two years' activities, is particularly marked by the change in climatic conditions. It is likely that any shoot that ceases elongation growth early enough to allow an interval sufficient to mature itself and accumulate necessary reserves before the critical time of differentiation may form a flower-bud. As the shoots of the first flush and the relatively early ones of the subsequent flush are most likely to cease growth early enough, they are the ones most likely to flower in the following year. And it is believed that although shoots of the first (March) flush have only been used in the present study the critical time of bud differentiation determined is good for the tree as a whole for all practical purposes. It may, however, be interesting to study the shoots of the different flushes separately with a view to elucidating the subject further.

SUMMARY AND CONCLUSION

The importance of the knowledge of the time of flower-bud initiation of the mango in the study of the problem of its alternate bearing has been pointed out.

The time has been determined using 15-year-old Langra mangoes which were in good health but had already developed alternate bearing habit.

Terminal buds on shoots of the earliest flush (March flush) which are the ones most likely to flower in the following year were collected at suitable intervals between June and the following January when the buds begin to break open. Radial longitudinal microtome sections of these buds were studied. The presence of protrusions in the axils of bud scales was used as the criterion for detecting flower-bud differentiation (Plates VII and VIII).

The study was made in the three consecutive years of 1937, 1938 and 1939. In the first and third years the trees were in their ' off ' years while in 1938 they were in their ' on ' year.

In all the three years flower-bud differentiation was first detected after the end of September. Although the shoots had ceased growth as early as June-July, no differentiation could be detected earlier.

There is an interval between the time of cessation of growth and that of bud differentiation. It is believed that the shoots mature and accumulate appropriate reserves during the interval.

In 1938 when the trees were in their ' on ' year flower-bud differentiation was first detected a fortnight later than in 1937 and 1939. This year flower-bud formation was poor.

The progressive increase in the number of differentiated buds from the beginning of October to the middle of November, especially in the ' off ' years of 1937 and 1939 when flower-bud differentiation was greatly favoured, indicates the extent of the period of active differentiation.

The sharp change in climatic conditions brought about by the end of September, namely the advent of cold and dry weather, appears to be one of the determining factors for fruit-bud differentiation of the mango.

For all practical purposes the month of October and the first half of November, under Sabour conditions, i.e. a period of about five to six weeks immediately preceding the period of cessation of growth in November-December may be taken as the critical time for flower-bud differentiation. In localities where flowering occurs some time earlier or later than at Sabour, the time of flower-bud differentiation and also the period of cessation of growth would vary accordingly.

In conclusion, the authors wish to thank the Imperial Council of Agricultural Research under whose scheme the work was done. Thanks are also due to Dr H. K. Mookerji, Professor of Zoology, Calcutta University, for affording the facilities, and to Mr M. M. Chakravarty, Lecturer in the same Department, for kindly taking the microphotographs.

REFERENCES

Chandler, W. H. (1925). *Fruit growing*, Chapter II : Houghton Mifflin Company, New York

Gibbs, A. M. and Swarbrick, T. (1930). *J. Pom. & Hort. Sci.* **8**, 61-6

Sen, P. K. (1939). *Ann. Rep. Fruit Res. Sta. Sabour (India) for 1937-38*, Part II, pp. 51, 54 ; *for 1938-39*, pp. 2, 5

Singh, Lal and Khan, A. A. (1940). *Ind. J. Agric. Sci.* **9**, 835

INVESTIGATIONS ON THE STORAGE OF ONIONS

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(With Plate IX and two text-figures)

I. Introduction

Onion (*Allium cepa*) is a very common cultivated crop in India. It is very widely used as a vegetable and relish by almost all classes of people in the country and, on account of its cheapness, is always in good demand. Onions can be kept for considerable periods in dry or ordinary storage, but losses due to sprouting, root-growth, fungal rots and driage under such storage conditions are often considerable. The bulbs can be preserved without loss for long periods, if kept under good ventilation and in dry air conditions. For example, onions are stored very effectively as braided bundles of bulbs harvested along with the leaves and hung on ropes or bamboos. Such a method, however, cannot be adopted on a large scale [Gokhale, 1929].

Onions come into the market in large quantities in the harvesting season, from March to May in the Bombay province, and the prices at that time almost always fall very low. It is, therefore, often advantageous to store the produce for some time so as to wait for better market rates. In the onion-growing tracts of the Bombay province, special storage houses are erected with grass-thatched roofs and with sides constructed of bamboos placed at intervals so that air can freely circulate. Even then, frequent inspection of the store, sorting out and removal of any rotting bulbs and turning over of the stored material are essential to successful storage. Otherwise, the loss by drying and rotting may come to as high a figure as 30 to 40 per cent of the total stored material. With proper ventilation and good care, this loss may be reduced to 15 to 20 per cent [Gokhale, 1929]. In lots held in ordinary storage for six months at Pusa, Walton [1928] recorded a loss of 58 per cent by weight in onions stored on racks and 46 per cent in bulbs stored in baskets. In the same experiment, the losses on account of rotting were 5·5 and 13·1 per cent of the initial weight respectively.

Cold storage has been found to be advantageous in the preservation of stored onions as, at low temperatures, the loss in weight is reduced and sprouting prevented. Rose, Wright and Whiteman [1933] found that a temperature of 32°F. with 70 to 75 per cent relative humidity was desirable for the successful storage of onions for five to six months. At higher humidities, onions were disposed to root-growth and decay. These authorities have stated that about one-third of the onion crop of the northern onion-growing States in the U. S. A. is put into cold storage before the winter months for consumption late in the spring. Platenius, Jamison and Thompson [1934] found that onions kept in perfect condition at 30° and 32°F. for six months. At these temperatures, the relative humidity of the air was found to be of little importance and onions remained dormant and free from decay for the entire storage period in an atmospheric humidity of 95 per cent or higher. Cleaver [1934] observed that both low temperature and low atmospheric humidity were important considerations in onion storage, but of these two factors temperature was considered to be more critical. High temperature induced early sprouting—the most important cause of losses—and, as a result of his observations, he recommended that onions should be stored as near 32°F. as possible.

Wright, Lauritzen and Whiteman [1932], working with Yellow Globe onions stored at 32°, 40° and 50°F. under low, medium and high humidities, recorded that the bulbs sprouted least at the lowest temperature. Their investigations showed that the relative humidity had little influence on sprouting, but root formation, on the other hand, increased consistently with the humidity and bore little relation to temperature. The same investigators [1935] made further observations on the storage of several other varieties of onions and concluded that the amount of sprouting occurring during the storage was influenced little by humidity but definitely by temperature. The amount of decay showed only a slight tendency to increase as both temperature and relative humidity were increased, and most of the decay was identified as ‘ neck-rot ’. They concluded that the best storage environment for onions was 32°F. with a relative humidity of about 64 per cent.

A series of experiments were carried out in connection with the cold storage of onions by Williams [1937] in Australia. It was proved that onions could be kept in good order and condition in cold storage for several months. Several packages of onions of the two varieties, Brown Spanish and Silver Skin, were placed in cold storage at various temperatures ranging from 25° to 35°F. and the best results were obtained from a temperature of 32°F. with a humidity of 87 per cent. Heiss [1937] carried out investigations on the gas-storage of onions and the results of his experimental work indicated the very definite superiority of nitrogen gas storage over ordinary cold storage.

In India, considerable losses are experienced annually in the storage of onions, but no work has yet been carried out on improvement in the methods of storage at the different producing centres. Storage investigations on onions were started in 1937 under the Cold Storage Research Scheme, Ganeshkhind Fruit Experiment Station, Kirkee, financed by the Imperial Council of Agricultural Research, and the results so far obtained are reported in this paper.

II. TEMPERATURE OF STORAGE

There are two common varieties of onions cultivated in the Bombay province, the White and the Red. Preliminary storage trials in 1937 with both these varieties showed that the onions sprouted more quickly at 52°F. than at higher or lower temperatures. At 52°F. the bulbs commenced sprouting after six weeks. At 32°F. they remained without sprouting for more than six months, while at a temperature maintained between 75° and 85°F. only a few of the bulbs had sprouted at the end of a year. However, most of the onions kept at such a high temperature of storage got dried up considerably after eight months of storage. Further experiments were made with onions of the Red variety only as they are more readily available in the Poona market.

Sprouting and root growth

The influence of the temperature of storage on the rate of sprouting and root growth was determined in 1938. A hundred onions, selected for uniform size and stage of maturity, were kept in trays at each of the temperatures, 32°, 35°, 40°, 48°, 52°, 60°, 68°, 75°-85°, 90°-95°F., and at room temperature (laboratory room), which varied considerably during the period of the experiment. The temperatures of 75°-85°F. and 90°-95°F. were maintained in cabinets by the use of electric lamps. The relative humidity in the chambers at the temperatures of 32° to 68°F. was generally between 80 and 90 per cent. At 75°-85°F. and at 90°-95°F. humidity was not controlled in any way but varied according to the outside atmospheric conditions.

The onions were examined every fortnight when the number of onions which showed sprouting or root growth was recorded. The resultant data are given in Table I. It will be observed that onions stored at 48°, 50° and 60°F. sprouted earlier than those kept at higher or lower temperatures. The range of temperatures between 48° and 60°F. appeared to be more conducive to the sprouting of onions, 60°F. being the optimum temperature in this respect. This range of temperatures is reached at many places in Northern India during winter and this may be, perhaps, the reason why most of the onions obtainable in the ordinary markets during the cold weather months are sprouted and shrivelled in appearance. At 32°F. the onions remained dormant for six months but commenced sprouting in the seventh month. At 75°-85°F., sprouting was negligible and at 90°-95°F. there was practically no sprouting, only two bulbs (which had rotted) showing the development of weak sprouts after eight months of storage. At room temperature, there was no sprouting as long as the minimum atmospheric temperature was high (70°F.) but sprouting commenced as soon as it decreased below 60°F. in the winter months.

There was no root growth at 75°-85°F. or at 90°-95°F., but at the lower temperatures new roots were produced. The difference in the periods required for new roots to appear at the different lower temperatures indicated that such root formation was related to temperature, the relative humidity being equal at all these temperatures. It was also observed that sprouting was not in any way connected with root formation as many bulbs sprouted without the appearance of new roots. That a high humidity is necessary for root formation was seen from the observation that a few bulbs kept at

TABLE I

*Rate of sprouting and root formation of onions at different temperatures**

Storage period in months	32°F.		35°F.		40°F.		48°F.		52°F.		60°F.		68°F.		75°-85°F.		90°-95°F.		Room temperature		
																			Mini-mum		
	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	(°F.)	S.	R.
1 (June-July)	0	0	0	0	0	0	0	100	3	98	4	0	0	0	0	0	0	0	70	0	0
2	0		0	49	2	98	28	...	22	...	60	91	12	39	0	0	0	0	70	0	0
3	0	65	1	95	32	...	75	...	51	...	83	...	24	68	1	0	0	0	70	0	1
4	0	87	12	...	66	...	89	...	73	...	93	...	35	82	1	0	0	0	72	0	5
5	0	...	53	...	92	...	95	...	79	...	99	...	40	...	3	0	0	0	58	6	...
6	6	...	89	...	99	...	100	...	87	...	100	...	55	...	4	0	0	0	50	16	...
7	31	...	97	...	100	...	...	...	93	...	...	...	72	...	5	0	0	0	46	36	...
8	57	...	...	...	...	...	...	...	94	...	...	...	84	...	6	0	1	0	52	44	...
9	89	...	...	...	...	...	...	...	100	...	...	...	...	...	...	0	2	0	51	50	...
10	100	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0	2	...	52	...	...

* S represents the percentage of sprouting and R the rate of root formation

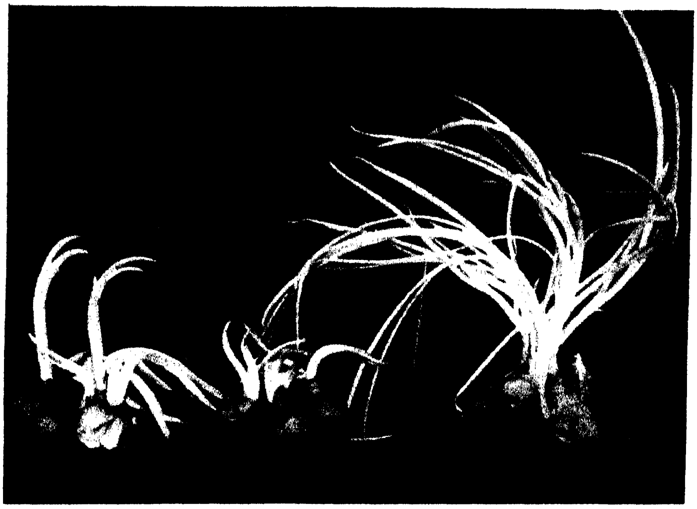
52°F. in a desiccator, with calcium chloride as the drying agent, did not show root growth. In another experiment, the bottom end of the bulbs was covered with melted paraffin wax in order to prevent the effect of moisture on root development in the storage atmosphere. In this experiment, no growth of new roots was visible at the root-end of the onions. On opening the bulbs, however, it was observed that root growth had taken place, but was underneath the outer red scale and extended towards the neck-end of the bulbs.

Fungal rotting

In the storage experiments described above rotting was not observed to any appreciable extent at any of the storage temperatures tested. Fungal growth appeared on the tips of new roots formed in storage but was limited to the roots only and did not attack the bulbs. The temperature of 75°-85°F. is not much above the atmospheric temperature in the rainy season at Poona and hence the relative humidity in the storage cabinet was approximately equal to the atmospheric humidity. The onions stored at 75°-85°F. became damp during the monsoon months and gradually showed the appearance of a black mould on the outer scale. At 90°-95°F., a temperature higher than the normal atmospheric temperature, the onions remained dry and rustled when handled. There was no wastage for the first eight months of storage at 90°-95°F. On prolonged storage at this temperature, however, some of the less mature onions became dried up and developed black mould or were attacked by small insects (thrips). A few of the bulbs also showed soft rot.

Effect of temperature of storage on the subsequent rate of sprouting

For this experiment, onions were stored at 32° and at 90°-95°F. Two samples, each consisting of 25 bulbs, were taken from each of these temperatures after 1, 3, 5 and 7 months of storage respectively and kept at 52° and at 68°F. The rate of sprouting after removal to these temperatures was determined. The resultant data are given in Table II. It was observed that storage at 32° or at 90°-95°F. hastened the rate of sprouting which also increased with the length of the storage period. The rate of sprouting of onions stored at 32°F. was higher at 68° than at 52°F. More than half of the onions stored for five months at 32°F. sprouted at 68°F. within three days after removal from the low temperature, and within a week at 52°F. The onions stored at 90°-95°F. for five and seven months remained without sprouting at 68°F. for ten and seven days respectively. These observations indicated that onions stored at 32°F. for more than three months should be consumed soon after removal from cold storage, whereas the onions stored at the high temperature of 90°-95°F. did not sprout until at least a week after removal to atmospheric temperatures of between 50° and 70°F., this period being available therefore for the distribution to consumers. The sprouting capacity of onions was not impaired in storage either at 32° or at 90°-95°F. as almost all the bulbs subsequently sprouted satisfactorily when removed



IG. 1. Sprouting of onions at 52° and 68° F. after removal from the storage temperature of 32° and 90°-95° F.

A B

FIG. 2. Fully mature (A) and immature (B) onions

to temperatures of 52° and 68°F. (Plate IX, fig. 1). The sprouts from onions stored at 90°-95°F. appeared to be sturdier than from those stored at 32°F.

Relation of the size of onions to the rate of sprouting under storage conditions

One hundred onions of large size (average weight 120 gm.) and of small size (average weight 60 gm.) were kept at 52°F. and the rate of sprouting was determined. It can be seen from the results given in Table III that the large onions sprouted more quickly than the small ones. Similar results were also obtained at 32°F. after six months of storage when the bulbs commenced sprouting.

TABLE II

Effect of the storage temperature on the subsequent rate of sprouting after removal to 52° and 68°F.

Number of days after removal	Percentage of sprouted onions							
	At 52°F. Period of storage in months				At 68°F. Period of storage in months			
	1	3	5	7	1	3	5	7
	Stored at 32°F.							
3	0	0	4	48	0	0	56	64
7	0	0	68	80	0	8	88	88
10	0	12	88	92	0	36	92	88
14	0	28	96	92	0	44	92	92
22	12	40	100	..	4	52	96	..
	Stored at 90°-95°F.							
3	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	12
10	0	0	4	48	0	0	0	44
14	0	0	20	56	0	0	12	52
22	0	0	68	88	0	12	48	68

TABLE III

Rate of sprouting of large and small onions at 52°F.

Storage period in weeks	Percentge of sprouted onions	
	Large	Small
2 . .	0	0
4 . .	2	0
6 . .	18	5
8 . .	57	28
10 . .	72	55

III. LOSS IN WEIGHT OF ONIONS IN STORAGE

Relation of the size of the bulbs to the rate of loss in weight

In 1937, onions of two sizes, large (average weight 120 gm.) and small (average weight 60 gm.) were kept at 30°, 40°, 52° and 68°F. and the loss in weight in storage was determined. The results are given in Table IV, from which it can be seen that the percentage loss in weight of the small onions was higher than that of the large ones at all the four temperatures of storage under experiment.

TABLE IV

Rate of loss in weight in storage of large and small onions

Number of days of storage	Percentage loss in weight							
	30°F.		40°F.		52°F.		68°F.	
	Large	Small	Large	Small	Large	Small	Large	Small
6	0·85	0·85	0·75	1·23	0·86	1·26	1·63	1·90
15	1·71	1·97	1·44	2·55	1·91	2·36	2·90	3·22
22	2·49	2·82	2·06	3·17	2·97	3·71	3·75	4·46
30	3·02	3·51	2·44	3·96	3·57	4·33	4·18	4·74
38	3·48	4·28	2·94	4·76	4·43	5·05	4·67	5·60
46	3·94	4·88	3·44	5·64	5·15	5·91	5·24	6·26
54	4·53	5·74	4·07	6·04	5·81	6·54	5·52	6·74

Influence of the storage temperature on the rate of loss in weight of onions

The relative loss in weight of onions at different storage temperatures ranging from 32° to 90°-95°F. was determined. Fully developed onions of uniform size (each weighing about 70 gm.) were selected and a sample was kept at each of the temperatures used. Each sample consisted of 20 bulbs which were kept in a small tray. The samples were weighed every month and the loss in weight was determined. The results obtained are given in Table V.

TABLE V

Relative loss in weight of onions at different temperatures

Period of storage in months	Percentage loss in weight							
	32°F.	35°F.	40°F.	48°F.	52°F.	68°F.	75°-85°F.	90°-95°F.
1	1·07	1·60	2·32	3·25	3·24	2·84	3·00	5·06
2	2·28	3·49	5·51	*7·56	*7·69	*5·67	5·85	8·43
3	3·71	5·65	*9·49	11·59	12·29	9·03	8·21	11·43
4	5·77	*8·29	13·41	15·19	17·40	12·23	10·92	14·87
5	7·77	11·36	17·68	18·80	..	15·43	14·63	18·09
6	10·20	15·05	22·10	..	..	19·69	20·20	21·13
7	*12·33	18·67	26·01	..	..	25·02	26·20	26·29
8	14·40	22·58	..	..	..	..	33·48	31·37
9	16·90	..	..	..	..	..	39·48	38·32
10	..	..	..	..	..	..	..	43·71

* Sprouting commenced

The values of the percentage loss in weight at 32°F. and 90°-95°F. have been represented graphically in Fig. 1. It can be observed that there was a steady increase in the rate of loss in weight of the samples stored at 32°F. In the early stages of storage, the loss in weight of samples stored at 90°-95°F. was much higher than of those at 32°F., but after six months of storage, when the onions stored at 32°F. commenced sprouting, the loss of weight in the bulbs kept at 90°-95°F. was only roughly double that of those kept at 32°F. The rate of loss in weight during storage at 90°-95°F. remained constant for the first six months. There was then an increase and this change in the rate occurred when the loss in weight had reached more than 20 per cent of the original weight and the outer scale was completely dried up. It was found that the outer scale of an onion of the size used in this experiment formed about 20 per cent of the total weight of the bulb. When the outer scale became dried up, transpiration commenced to take place directly from the next inner scale. There was then a change in the rate of loss in weight, possibly because transpiration occurred from a fresh scale and also because the volume of the bulbs decreased with an increase in the surface-bulk ratio.

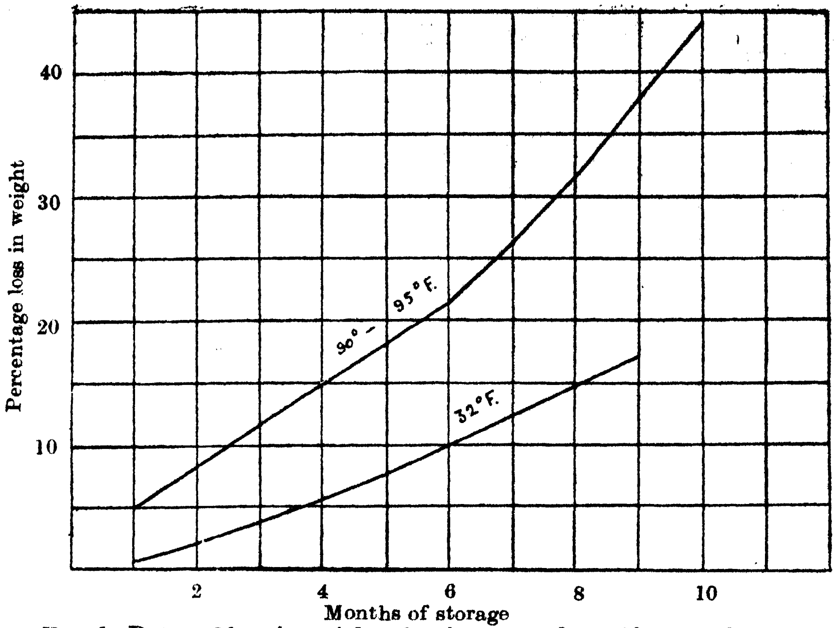


FIG. 1. Rates of loss in weight of onions stored at 32° and 90°-95°F.

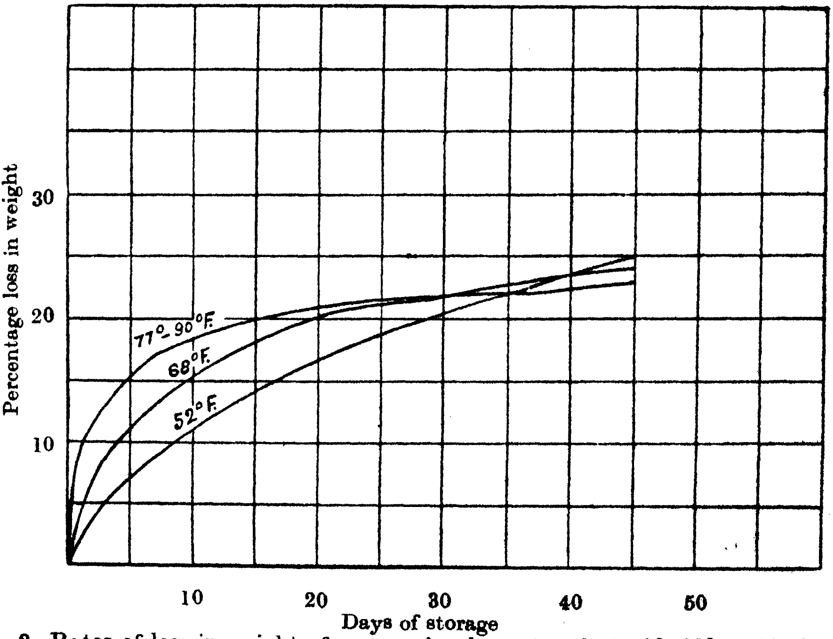


FIG. 2. Rates of loss in weight of 'young' onions stored at 52°, 68° and 77°-90°F.

In 'young' onions, the rate of loss in weight was very rapid in the beginning of storage at 52°, 68° and 77°-90°F. until the outer scale was dried up and the thin red coat or membrane was formed. This occurred when the loss in weight was about 20 per cent of the initial weight. After this the rate of loss in weight considerably slowed down (Fig. 2). The red coat appeared to serve as a good protection against transpiration. To minimize loss in weight, therefore, it would appear to be necessary that sufficient care is taken in handling onions in storage so that the red coat is not damaged or removed but remains intact.

The experiments described above to determine the loss in weight of onions stored at different temperatures were made by using only a few bulbs in each sample. In another experiment, the loss in weight in storage was determined with bigger samples. About 80 lb. of onions were packed in trays and kept at 32° and also at 90°-95°F. The results obtained showed that with larger quantities also the loss in weight at 90°-95°F. was nearly double the loss at 32°F.

Influence of the stage of maturity of the onions on the loss in weight

In the 1938 storage trials at temperatures of 32° and at 90°-95°F., it was observed that the stage of maturity or development of the onions was not so important a factor in loss of weight at the former as at the latter temperature. At 90°-95°F. onions which were immature, *i.e.* harvested before the leaves were completely dried up in the field and the bulbs were not fully ' capped over ' and which were of ' thick neck ', rapidly lost water and became desiccated. In one sample consisting of 20 immature bulbs weighing 1,400 gm. at the time of placing in storage at 90°-95°F., the weight of the sample at the end of 10 months of storage was only 58 gm.

In 1939, two lots of onions, one of bulbs fully mature or completely ' capped over ' (Plate IX, fig. 2A) and the other of bulbs ' just mature ' but of thicker neck (Plate IX, fig. 2B), were stored at 90°-95°F. and the loss in weight was determined. The weight of each sample was about 80 lb. and the onions were packed in trays. The results given in Table VI show that the loss in

TABLE VI

Relative loss in weight of fully mature and ' just mature ' onions at 90°-95°F.

Period of storage in months	Percentage loss in weight	
	Fully mature	Just mature
1	2·12	4·17
2	4·25	7·68
3	7·30	9·84
4	11·10	14·52
5	13·68	19·36
6	18·84	25·87
7	24·92	32·06
8	32·06	41·41

weight of the 'just mature' onions was greater than that of the fully mature ones. Woodman and Barnell [1937] have demonstrated that the loss in weight takes place mainly by evaporation of water from the inner surface of the scales and therefore mainly through the neck. The higher loss in weight from 'just mature' onions might therefore be due to the thicker neck of the bulbs, permitting increased evaporation of moisture from the interior.

IV. CHEMICAL CHANGES IN ONIONS AT DIFFERENT STORAGE TEMPERATURES

The pungency of onions remained unaffected in storage either at the low temperature of 32° or at the high temperature 90°-95°F.

Changes in the amount of water, total nitrogen, reducing, non-reducing and total sugars in onions during sprouting and during storage at 32° and 90°-95°F. were determined. Ten bulbs were used for each sample. The outer red scale and the inner whorl of scales containing the dormant green shoots or buds were removed and the remaining portion of the bulb was cut into small pieces. The methods described by Cheema, Karmarkar and Joshi [1939] were used for the analyses. The results are given in Table VII.

TABLE VII

Changes in the chemical composition of onions during sprouting and in storage at 32° and 90°-95°F.

Stage of maturity	Percentage of water	Percentage of total nitrogen	Percentage of reducing sugars	Percentage of non-reducing sugars	Percentage of total sugars
			During sprouting		
Dormant (fresh)	87·9	0·120	2·97	5·67	8·64
Just sprouting	87·2	0·150	3·86	4·78	8·64
Sprouts one inch long	88·3	0·150	3·60	4·71	8·31
Sprouts two to three inches long	87·2	0·129	3·55	4·42	7·97
			Stored at 32°F.		
Storage period in months					
5	87·4	0·136	5·17	4·05	9·22
7	87·3	0·128	5·10	4·00	9·10
			Stored at 90°-95°F.		
5	87·2	0·184	2·27	5·60	7·87
7	86·5	0·208	1·64	6·66	8·30
9	87·4	0·210	1·59	6·06	7·65
11	85·3	0·250	1·55	5·90	7·45

These results show that, during sprouting, there were no marked changes in the chemical composition of the pulp, except that there was an increase in the percentage of total nitrogen and that the percentage of reducing sugars rose slightly. In onions stored at 32°F., there was a very marked increase in the amount of reducing sugars and also an increase in the amount of total sugars. In onions stored at 90°-95°F., the amount of reducing sugars decreased considerably, showing an increase in the amount of non-reducing sugars as the percentage of total sugars remained unaffected. At this high temperature of storage the percentage of total nitrogen steadily increased, indicating that there was a transfer of nitrogen from the inner whorl of scales containing the green shoots.

V. RATE OF RESPIRATION OF ONIONS IN STORAGE

The rate of respiration of onions during storage at 52° and 32°F. was determined. The results are given in Table VIII, from which it can be seen that the rate of respiration increased during storage. At 52°F., there was a sudden increase, the value becoming double the original value after 10 days of storage. At 32°F., the increase may be due to the increase in the amount of reducing sugars. The rate of respiration has been expressed in terms of c.c. of carbon dioxide at 68°F. produced per 100 gm. per 24 hours.

TABLE VIII

Rate of respiration of onions during storage at 52° and at 32°F.

52°F.		32°F.	
Number of days of storage	Rate of respiration	Period of storage in months	Rate of respiration
0 . . .	4·1	0	2·0
10 . . .	8·0	1	2·9
24 . . .	8·8	2	3·2
38 . . .	10·3	3	3·5
52 (started sprouting)	11·2	4	4·0
		5	4·0

VI. SUMMARY

1. The results of the investigations carried out from 1937 relating to the storage of onions (*Allium cepa*) have been described.

2. Onions sprouted more quickly at storage temperatures from 48° to 60°F. than at higher or lower temperatures. At 32°F., they remained dormant in storage for six months, while at the high storage temperature of 90°-95°F. they did not sprout at all. The storage at 32° and 90°-95°F. increased the rate of subsequent sprouting when the bulbs were removed to temperatures of 52° or 68°F. At these temperatures, the onions removed from previous storage at 32°F. sprouted earlier than those from 90°-95°F. Thus more than

50 per cent of the onions stored at 32°F. for five months sprouted within three days after removal to a temperature of 68°F., while onions stored at 90°-95°F. for an equal period remained at 68°F. without sprouting for 10 days. New roots were produced in storage at 32°F., but at 90°-95°F. there was no root formation. The size of the bulbs appears to influence the rate of sprouting as, in storage at 52°F., large bulbs sprouted at a faster rate than small ones. There was no rotting during the first eight months of storage at 90°-95°F.

3. Small onions lost weight more rapidly in storage than large ones. The percentage loss in weight of onions stored at 90°-95°F. for six months (21 per cent) was roughly double the loss on storage for a similar period of time at 32°F. The stage of maturity of the stored onions greatly influenced the loss in weight in storage at 90°-95°F., onions which were fully developed or completely ' capped over ' at the time of harvesting losing the least in weight.

4. The pungency of the onions remained unaffected in storage either at 32° or at 90°-95°F. There were no marked changes in the chemical composition of onions during sprouting. In storage at 32°F. there was a very marked increase in the amount of reducing sugars and also an increase in the amount of total sugars. In storage at 90°-95°F. the percentage of total sugars in the bulbs did not alter, but the percentage of reducing sugars decreased, thus increasing the proportion of non-reducing sugars.

5. The rate of respiration increased during storage. At 52°F. there was a sudden increase after storage commenced. At 32°F., the increase in the respiration rate during storage may be due to the increased concentration of reducing sugars.

ACKNOWLEDGEMENTS

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REFERENCES

Cheema, G. S.; Karmarkar, D. V. and Joshi, B. M. (1939). *Imp. Counc. Agric. Res. (Ind.) Misc. Bull.* **21**

Cleaver, H. M. (1934). *Indiana Sta. Bull.* **393**

Gokhale, V. G. (1929). *Dept. Agric. Bombay, Leaflet* **12**

Heiss, R. (1937). *Bull. Int. Inst. Refrig. Abstract* **69**

Platenius, H.; Jamison, F. S. and Thompson, H. C. (1934). *Cornell Agric. Expt. Sta. Bull.* **602**

Rose, D. H.; Wright, R. C. and Whiteman, T. M. (1933). *U. S. Dept. Agric. Circ.* **278**

Walton, J. H. (1928). *Agric. J. Ind.* **23**, 136

Williams, W. J. (1937). *Australian Refrigeration Review of 1937*, p. 21

Woodman, R. M. and Barnell, H. R. (1937). *Ann. Appl. Biol.* **24**, 219

Wright, R. C.; Lauritzen, J. I. and Whiteman, T. M. (1932). *Proc. Amer. Soc. Hort. Sci.* **29**, 463

———————————— (1935). *U.S. Dept. Agric. Tech. Bull.* **475**

*A NEW MICRO-IODINE METHOD FOR THE DETERMINATION OF STARCH IN PLANT MATERIAL

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IT has been shown elsewhere [Chinoy, Edwards and Nanji, 1934] that under certain standard conditions the amount of iodine present in the iodide-complex is constant, and that if these conditions are observed, it is possible to determine starch accurately and rapidly. Conditions were standardized for the precipitation of starch iodide and weighing it as such. This gravimetric starch-iodide method has already been successfully used for determining soluble starch, pure commercial starches, as well as starch in flours, potato tubers and various leaf materials [Chinoy, Edwards and Nanji, 1934 ; Chinoy, 1938].

The success of all these methods for the accurate determination of starch in plant material depends largely upon its complete extraction.

During the investigations of the cotton failure problem [Dastur, 1939] it was found by microscopic examinations of the leaves that starch accumulation occurred in leaves of 4F American cotton plants that produced badly opened bolls. A necessity, therefore, arose to devise a suitable method for determining starch quantitatively in order to support the microscopic observations. It was, therefore, attempted to develop a micro-technique on the lines already described [Chinoy, 1938] for the determination of starch in leaves, roots, stem and reproductive parts of the cotton plant. Under the standardized conditions outlined below it is possible to work with only 0·1 to 0·3 gm. of plant material instead of 1-5 gm. generally taken in the current methods [Chinoy, 1938 ; Widdowson, 1931]. It has an advantage as extraction is facilitated and a larger number of analyses can be carried out in the same amount of time.

EXPERIMENTAL

Soluble starch and pure commercial starches

In the first instance experiments were carried out with pure soluble starch and wheat and rice starches in order to determine the recovery on a micro-scale. Aliquots of 5 ml. from standard starch solutions were pipetted out in clean test-tubes and starch was determined. The results are given in Table I.

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*This work was done in the Punjab Physiological (Cotton Failure) Scheme financed by the Indian Central Cotton Committee.

TABLE I

Recovery of starches

Calculated		Found	
Starch analysed	Starch (dry weight) per cent	Starch iodide in 5 ml. aliquot (mg.)	Starch (dry wt.) per cent
Soluble	0·2796	1·598	0·2818
,,	0·2796	1·577	0·2796
Rice	0·5412	2·957	0·5242
,,	0·5412	2·993	0·5306
,,	0·5412	2·945	0·5221
,,	0·5412	2·923	0·5182
,,	0·5412	2·952	0·5234
,,	0·5412	2·957	0·5242
Wheat	0·5930	3·290	0·5833
,,	0·5930	3·315	0·5877
,,	0·5930	3·301	0·5851
,,	0·5930	3·364	0·5966

The results show that micro-filter tubes are suited for the gravimetric determination of starch iodide on a micro-scale.

Extraction of starch from plant material

Suitable aliquot parts (0·1 to 0·3 gm.) from the dry powder are weighed accurately and placed in specially prepared centrifuge tubes. These centrifuge tubes were made in the laboratory. About 0·5 gm. of fine, purified sand and approximately 1 ml. of 0·7 per cent KOH solution are added to each tube and the plant material is crushed for about five minutes against the bottom of the tube with a glass rod. The mixture is made into a paste by the addition of another 9 ml. of the KOH solution. The tubes are placed in a boiling water-bath for one hour. After about one hour's heating the tubes are removed from the bath and centrifuged. Four extractions are usually sufficient to remove all the starch. After the centrifuging and the decantation of the fourth extract about 5 ml. of water are added and the material is shaken and centrifuged. In case the blue colour persists in the washing a fifth extraction is made.

Determination of starch

For the determination of starch the general procedure for neutralization of the alkali, addition of iodine and precipitation of starch iodide by addition of potassium acetate is the same as described previously [Chinoy, 1938]. It is, however, necessary to reproduce here in detail the micro-technique used for precipitation and filtration.

The requisite amount of the solution (1 to 5 ml. or more), as ascertained by the preliminary test, is pipetted into a centrifuge tube and neutralized with the necessary quantity of 10 per cent acetic acid, and 0·5 ml. of 0·1 *N* iodine solution (which must be in excess) and 2 ml. of 10 per cent potassium acetate solution are added. The precipitate thus obtained is kept overnight (if necessary) for proper coagulation.*

The solution together with the precipitate is centriguged. About 10 ml. of 30 per cent alcohol are added to the precipitate, and, after thorough mixing, filteration and washing of the starch iodide precipitate is carried out as follows in a micro-filter tube originally used by Pregl [1937].

The whole of the precipitate and liquid are siphoned into a tared micro-filter tube[1] by applying gentle suction. The sides of the centrifuge tube are then washed with about 3 ml. of 50 per cent alcohol and the liquid is sucked in. This operation is repeated twice with 3-4 ml. of 95 per cent alcohol. The siphon is now disconnected and the precipitate is washed twice with 95 per cent alcohol by filling the filter tube each time.

Finally absolute alcohol is aspirated once through the tube. The filter tube is dried in the oven at 70°C. for one hour and weighed. The weight of the starch is obtained by multiplying the weight of starch iodide by the factor 0·8865.

Determination of starch in plant material

The above micro-method was used for the determination of starch in a study of the carbohydrate accumulations in leaves, stems, roots, buds and bolls of the 4F Punjab-American cotton. Detailed account of this investigation will be given elsewhere. It is intended to present here some select data indicating the accuracy and efficiency of the above method.

TABLE II

Plant material	Sample analysed (gm.)	Aliquot taken (ml.)	Starch iodide found in aliquot part (mg.)	Starch (dry weight) per cent
4F cotton root	0·1136	10	1·958	7·64
,, ,, ,, ...	0·2130	5	1·818	7·57
,, ,, ,, ...	0·0645	10	1·171	8·22
4F cotton stem	0·3960	5	4·306	9·64
,, ,, , ...	0·1560	10	3·631	10·27
,, ,, ,, ...	0·4210	10	9·834	10·36
4F cotton leaf	1·0850	10	10·781	4·40
,, ,, ,, ...	0·8200	10	8·044	4·35
,, ,, ,, ...	0·5976	3	1·744	4·31

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* In the case of the cotton plant the necessary coagulation was obtained within two hours.

[1] Asbestos is previously cleaned by repeated treatments with sulphuric-chromic acid and hot nitric acid and then washed with distilled water till free from acid. It is then suspended in distilled water ready for use.

TABLE II—*contd.*

Plant material	Sample analysed (gm.)	Aliquot taken (ml.)	Starch iodide found in aliquot part (mg.)	Starch (dry weight) per cent
4F cotton flowers and buds (I)	0·6608	10	4·412	2·96
,, ,, ,, . .	0·6608	10	4·353	2·92
4F cotton flowers and buds (II)	0·7870	10	6·879	3·87
,, ,, ,, . .	0·7870	10	6·837	3·85
4F Bolls : mature carpels (I) .	0·5118	5	3·122	5·41
,, ,, ,, (I) .	0·2535	10	3·267	5·71
,, ,, ,, (I) .	0·2535	10	3·289	5·75
4F Bolls: young green carpels (II) . . .	0·7224	3	7·153	14·63
,, ,, ,, (II) .	0·1208	10	4·107	15·07
,, ,, ,, (II) .	0·1208	10	4·126	15·14

DISCUSSION OF THE RESULTS

It will be noted that the starch content in the duplicates of the same extract agree very closely. Differences observed in the figures for separate extractions are of the order of 5-7 per cent. These differences are more pronounced in the case of stem and root. The microscopical examination of the root and stem powder reveals characteristic differences in the size and shape of the particles from those of leaf, flowers and buds, and carpel, even though all of them are passed through a 100-mesh sieve. Root and stem powders contain many more elongated fibrous particles in comparison to the powders obtained from leaf, flowers and buds, and carpel. This probably accounts for the greater discrepancy in the starch contents of separate extractions of root and stem samples. It is interesting to observe that even though the amount of the sample analysed varies considerably in some cases, it does not affect the accuracy of the determination appreciably.

The recovery of pure starch as well as the effect of the presence of pectin have already been noted for the macro-method [Chinoy, 1938]. The starch iodide method has already been compared with hydrolytic method of Widdowson [1931] and found to give usually much more consistent, though slightly lower, results than the Taka-diastase method. The starch iodide method is also found to compare well with the colorimetric method described elsewhere [Chinoy, 1939].

The present method is accurate and rapid as the extraction and estimations of 12 samples can be carried out at a time in a much shorter period than that taken by any hydrolytic method for the determination of starch.

The filtration, washing and drying of the starch iodide precipitate can also be accomplished in much less time than is the case in macro-methods. It is found that the micro-filter tube (used by Pregl for halogen determination) can be successfully used for the determination of minute quantities of starch in plant material.

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REFERENCES

Chinoy, J. J. (1938). *Analyst* **63**, 876
——————— (1939). *Mikrochemie* **26**, 132
Chinoy, J. J.; Edwards, F. W. and Nanji, H. R. (1934). *Analyst* **59**, 671, 672
Dastur, R. H. (1939). *Ind. J. Agric. Sci.* **9**, 285
Pregl, P. (1937). *Quantitative organic micro-analysis* (3rd English edition), pp. 96
Widdowson, E. M. (1931). *Biochem. J.* **25**, 863

STUDIES ON THE PHYSICO-CHEMICAL PROPERTIES OF ASSOCIATED BLACK AND RED SOILS OF NYASALAND PROTECTORATE, BRITISH CENTRAL AFRICA

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(With two text-figures)

THE NATURE OF TROPICAL BLACK SOILS AND THEIR CONTRASTING PROPERTIES WITH CLOSELY OCCURRING RED SOILS

THE tropical black soils have been divided into several varieties, e.g. black turf, black vlei soils, etc., but the differences amongst the several varieties are not at all well defined. The black soils of southern India are known as ' regurs ' and are in many respects analogous to the black turfs. Shantz and Marbut [1923] regard all these tropical black soils as being analogous to the tshernosem group of the temperate climates, but Marchand [1924] is of opinion that all tropical black soils are not of the same class. Theron and Niekerk [1934], however, think that ' the black turfs are undoubtedly soils belonging to the same family as Russian chernozems '. Dealing with some aspects of the black cotton soils of the Central Provinces, India, Bal [1935] points out that the occurrence of lime concretions is a common feature in the black cotton soils, but their exact position in soil profiles depends on the depth of the soil. The notable difference between the black turf and the vlei turf is that the C-layer of the latter is frequently mottled with blue, white, and green patches, indicating a low state of oxidation through periodic waterlogging. The clay contents of these tropical black soils vary from 40 per cent to 60 per cent, and the soils generally occur only in the sub-humid and semi-arid parts of the tropics under a rainfall of about 25 to 35 in. per annum.

Kenchington [1935] has made an interesting suggestion for differentiating two great groups of pedocalic soils. On either side of the equatorial humid zone there are practically rainless deserts. To the north of this belt, which is the zone of transition to the humic temperate regions, lies the classical ' tshernosem '. To the south in the zone of equatorial humid climate lies a class of pedocalic soils to which Kenchington assigns the name *teen-suda* which is a colloquial Arabic term commonly used by the Sudanese, meaning ' clay-black '. He thinks that the regur or black cotton soil of India and the so-called vlei soils of Africa are of the class of *teen-suda*.

Regarding the cause of the colour of black soil there are two main views expressed in the literature of the subject : (*i*) some peculiar state of combination of iron, and (*ii*) a peculiar type of humification in base-saturated soils due to the presence of limestone.

(*i*) Dealing with the black cotton soil or the ' regur ' of India, Annett [1910] thinks that ' the black colour of these soils is mainly due to 1-2 per cent of soluble humus '. He recognized that ' the mineral matter alone would not account for the deep black colour '. Harrison and Ramaswami Sivan [1912] could not find titaniferous magnetite to any significant extent in the black soils from the Bellary, Kurnool and Tinnevelly districts of India, and Maufe [1928] also was unable to show the presence of this titanium compound in the black soils of Salisbury in Southern Rhodesia. Harrison and Ramaswami Sivan hold that two classes of substances are responsible for conferring the colour and physical properties to the black cotton soils of India : ' One is probably a colloidal hydrated double iron and aluminium silicate, which is mainly concerned with the formation of compound particles and which possesses, in a modified form, the properties of ordinary clay. The other is organic in character and may possibly be an organic compound [Harrison and Ramaswami Sivan, 1912]. Dealing with the cause of the black colour of the black vlei soils at Salisbury in Southern Rhodesia, Maufe [1928] comes to the conclusion that ' the colour of the black vlei soils must be due to some peculiar, but undetermined, state of combination of the iron '.

(*ii*) The view that the black colour of the black turfs is due to a peculiar type of humification in the presence of limestone was suggested by Vipond [Marchand, 1924] as early as 1912. In a recent publication Theron and Niekerk [1934] have studied this question thoroughly, and from an analysis of their results they concluded that the black colour of the soil is a direct result of the mode of weathering in respect of both the organic and mineral constituent. This view has been supported by Van der Merwe [1935].

In a recent paper, Basu and Sirur [1938] have dealt with the survey and classification of the black soils occurring in the canal zone of the Bombay-Deccan. From an examination of a large number of profiles distributed over fairly representative parts of the Nira right bank and Pravara canals, eight soil types have been traced. These authors have put forward the suggestion that the ' colour of the soils seems to be more related with moisture relationships of soils than with the actual amounts of organic matter present. Fundamentally black-coloured soils are usually found on low-lying situations, where the soils remain moist over a considerable part of the year when compared with soils on a high level where the colour is usually brown. This brown colour also indicates some breaking down of the clay complex, due to high temperatures and extreme desiccation in the summer ' [Basu, 1939].

The nature of tropical red soils has been discussed by Raychaudhuri [1937].* Quite often, in the tropics, the black and red soils are found to occur side by side under apparently the same climatic and geological conditions, and the mode of formation of these soil types has been a debated problem. Marchand [1924] has discussed at length the question of the occurrence of dissimilar soils associated with similar rocks in South Africa. He points out that the texture of a soil ' will depend on the relative proportions of kaolin, silicic acid and ferric hydroxide, and these proportions are not necessarily the same for all rocks of similar mineralogical make-up '. The presence of iron compounds in the rock makes the resulting soil more open and easily drained. Moreover, sometimes an admixture of sandy material, perhaps from an adjacent quartzite or sandstone takes place, and the resulting soil is a red heavy loam.

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* Reference may also be made to the definition of laterite soil by Sen [1939].

Viswa Nath [1939] points out that in many places in Central and Southern India black and red soils occur together in the same district. Thus he points out that granites and gneisses give rise to black soil in some places and to red soil at other places. Where the soil is red, it is usually close to the hills and overlies a thin layer of decomposed granite and highly kaolinized felspar. With increase in the distance from the hills, black soil of increasing thickness occurs, and this is found overlying a thicker layer of decomposed and kaolinized material. This is suggestive of the conversion of red soil into black soil, but as Viswa Nath rightly points out, no direct experimental proof is yet available. The data presented by Viswa Nath show that black and red soils are differentiated by their base-exchange capacities, the black soils possessing much higher base-exchange capacities than the red.

The various considerations set forth above indicate that although the general characteristics of contrasted types of tropical red and black soils are more or less well known, their actual nature is still a debated problem. Much work remains to be done in this direction, and simultaneous morphological observations in the field and physico-chemical examination of profile samples in the laboratory are desirable.*

RESULTS WITH ASSOCIATED RED AND BLACK SOILS OF NYASALAND PROTECTORATE, BRITISH CENTRAL AFRICA

At Rothamsted Experimental Station, at the kind suggestion of Dr E. M. Crowther, the author had occasion to work with two contrasted soil profiles, red and black, occurring in close localities from Domira Bay† in the Nyasaland Protectorate. Soil samples‡ of these profiles were obtained up to 6 ft. depth in 9-in. cubic blocks. Table I shows the chemical composition of the clay fractions of some of the soil samples.

It will be seen from Table I that the clay fractions of both the black and red profiles have SiO_2/Al_2O_3 ratios greater than 2, and hence these soils should not be called laterite and lateritic in the sense of the definition of Martin and Doyne [1927]. It will also be noticed that in the case of both the profiles the SiO_2/Al_2O_3 ratio increases as the depth increases. The mineralogical studies of the soils which were kindly done by Dr Nagelschmidt at Rothamsted show that the heavy minerals of the fine sand fractions of both the black and red soils contain relatively more basic minerals, e.g. hornblende garnets, iron hydroxide, etc. This suggests that the parent materials of both soil types are basic in nature which fact might explain the gradual increase of SiO_2/Al_2O_3 ratio with increase in the depth of the soil profiles.

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* Reference may be made in this connection to the symposium on the black and red soils of Southern India, 1939, *Bulletin No. 2, Indian Society of Soil Science.*

† Domira Bay is a port of anchorage on the west coast of Lake Nyasa. The shorelands consist of recent alluvium. The average annual rainfall at Domira Bay is about 33 in. in summer. The rainfall is distributed from October to April, being heaviest towards the end of December and throughout January. Baobab trees are very common in Domira Bay soils. Columnar cracking is very marked in the black soils. The natives of Domira Bay do not like open black land, because they find it difficult to work by primitive methods. But it has been found that after two years of cotton, the black soils acquire friable structure and become easier to work.

‡ These profile samples were very kindly supplied by Mr H. C. Ducker,

TABLE I

Chemical composition of clay fractions

Colour of soil profile	Depth (in.)	Per cent loss on ignition on oven-dry basis	Molecular ratios		
			$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$
Black . . .	9—18	14·01	2·38	1·76	0·354
	27—36	12·83	2·38	1·77	0·343
	45—54	12·85	2·50	1·87	0·339
	63—72	12·03	2·75	2·02	0·359
Red	9—18	12·54	2·29	1·70	0·346
	27—36	12·82	2·25	1·70	0·322
	45—54	12·69	2·30	1·74	0·317
	63—72	12·49	2·44	1·84	0·328

If we consider equivalent layers of the black and red profiles, the clay fraction from the black soil appears to possess slightly higher ratios of silica/alumina and of silica/sesquioxide than the red soil. The difference, however, is not large. The average silica/sesquioxide ratio of the black and red clay fractions from Domira Bay soils is about 1·8.

Table II gives the data on the determination of the percentages of free silica, free alumina and free iron oxide in the clay fractions obtained from equivalent layers of the black and red soils. The method devised by Truog and Drosdoff [1935] was employed in the determination of these constituents.

TABLE II

Treatment of Domira Bay clays by Truog's method for dissolving free oxides of silica, aluminium and iron

Colour of soil-profile	Depth (in.)	Percentages of constituents dissolved by Truog's method		
		SiO_2	Al_2O_3	Fe_2O_3
Black . .	9—18	0·45	0·31	10·35
	63—72	0·20	0·66	7·95
Red . .	9—18	0·13	1·68	12·45
	63—72	0·13	2·16	10·82

The results in Table II show that by Truog's treatment more iron oxide is dissolved out from the red clay fraction than from the black. Also, the red clay fraction contains more free alumina than the black.* On the other hand, the black clay fraction contains more free silica than the red.

Determination of total organic carbon and of total nitrogen in the soils

Organic carbon in the soils was determined by following the rapid titration procedure devised by Walkley [1935] and total nitrogen was determined by Kjeldahl's method. The results are shown in Table III.

TABLE III

Percentages of total organic carbon and of total nitrogen

Colour of soil profile	Depth (in.)	C (per cent)	N (per cent)	C/N
Black . .	0—9	2·45	0·160	15·3
	9—18	1·13	0·092	12·3
	18—27	0·78	0·058	13·4
	27—36	0·65	0·046	14·1
	36—45	0·56	0·041	13·7
	45—54	0·38	0·029	13·1
	54—63	0·27	0·024	11·3
	63—72	0·18	0·021	8·6
Red . .	0—9	1·74	0·130	13·4
	9—18	0·79	0·078	10·1
	18—27	0·66	0·060	11·0
	27—36	0·54	0·058	9·3
	36—45	0·39	0·049	8·0
	45—54	0·31	0·043	7·2
	54—63	0·26	0·037	7·0
	63—72	0·23	0·035	6·6

It will be seen that the percentage of organic carbon decreases gradually with the depth of the soil layer. If we consider equivalent layers of the two profiles it will be noticed that the black profile contains a little more organic carbon than the red. It is, however, not likely that the black colour of black soils is due to this small excess of carbon, since it was observed that even after treatment with H_2O_2 or after continued leaching of the soils with a strong solution (10 per cent) of sodium carbonate for several days, the relative differences in the colours of the soils did not change to any appreciable extent. Also, if we consider equivalent layers of the two profiles the C/N ratios are higher for the black soils than for the red.

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* In a recent paper Raychaudhuri and Sulaiman [1940] have compared the percentages of free sesquioxides in Indian lateritic and red soils obtained by the methods of Hardy [1931] and of Drosdoff and Truog [1935]. Hardy's method yields higher values for percentages of free alumina but lower values of free iron oxide.

Mechanical analysis

Mechanical analyses of the soil samples show that there is no regular variation of the clay contents with the depth of the profile. The curves in Fig. 1 show that at the topmost layers the red soil contains much less clay than the black soil, whilst very low down (from a depth of approximately 55 in. downwards), the red soil contains much more clay than the black. At intermediate layers the clay contents of the two soils are very much the same. This characteristic depth distribution of the clay fractions in the soil types may be explained as being due to a greater degree of eluviation of clay in the red soil profile which indicates a better drainage condition of this soil type.

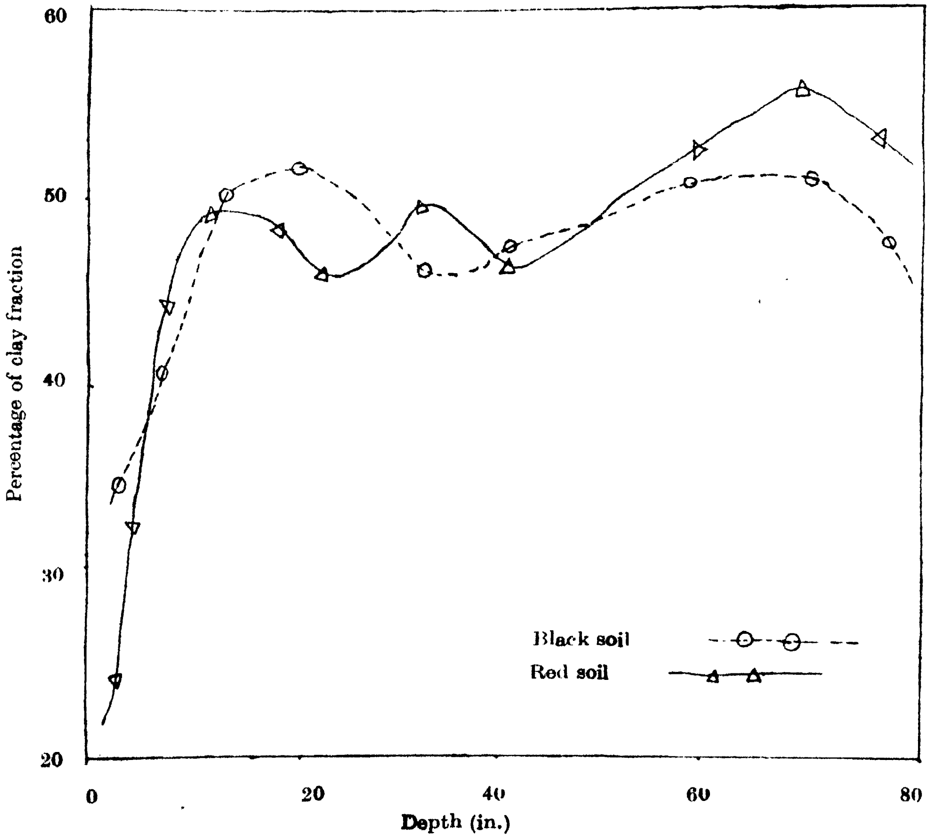

FIG. 1. Clay content of black and red soils

Examination of the buffer curves of the soil types

Fig. 2 illustrates the nature of buffer curves of two typical black and red soils obtained from equivalent depths (0 in.-9 in.) of the two profiles. The buffer curves were drawn following the procedure devised by Schofield [1933] and used by Raychaudhuri and Nandy Mazumdar with Indian red soils [1939, 1940]. The abscissa denotes the milli-equivalents of base taken up per 100 gm. of the soil material whilst the ordinate denotes the *p*H values at which the uptakes have taken place. It will be noticed that the curve for the black soil is flatter than that for the red, indicating that the black soil possesses greater buffer action. The probable explanation of the great buffering capacity of the black soil may be attributed to higher organic matter content as well as to the presence of higher amounts of free silica in the black soil. For an examination of the nature of organic matter in the soil profiles, a comparison was made of the properties of H_2O_2-treated soils with those of original soils. The results are shown in Table IV. The method for the determination of moisture equivalent was essentially the same as described by Keen and Raczkowski [1921]. The exact procedure followed was that described by Russell and Gupta [1934].

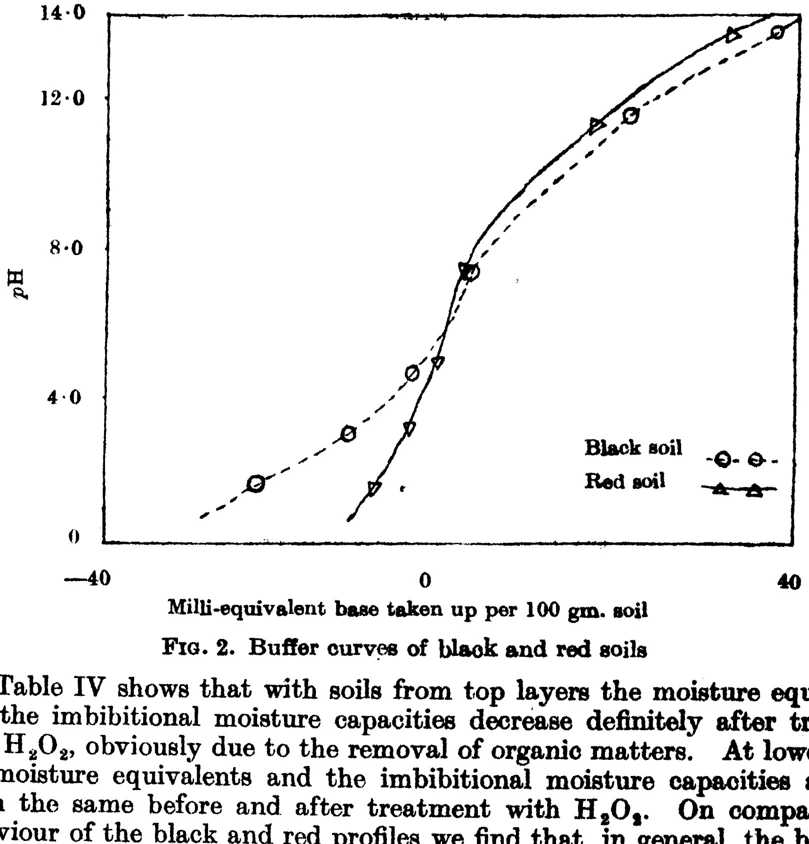

Fig. 2. Buffer curves of black and red soils

Table IV shows that with soils from top layers the moisture equivalents and the imbibitional moisture capacities decrease definitely after treatment with H_2O_2, obviously due to the removal of organic matters. At lower layers the moisture equivalents and the imbibitional moisture capacities are very much the same before and after treatment with H_2O_2. On comparing the behaviour of the black and red profiles we find that, in general, the black soil possesses higher values of moisture equivalent and imbibitional moisture capacities than the red soil, even after the soils have been treated with hydrogen peroxide. This is also remarkable, since the clay contents of the soil types are nearly the same and the chemical composition of the black and red clays are almost identical (Fig. 1 and Table I). The data on *p*H values, on exchangeable bases and on degrees of base-saturation of equivalent layers of the profile samples are shown in Table V.

TABLE IV

Moisture equivalent and imbibitional moisture capacities

Colour of soil profile	Depth (in.)	Original soil		H_2O_2-treated soil	
		Moisture equivalent	Imbibitional moisture capacity	Moisture equivalent	Imbibitional moisture capacity
Black	0—9	24·2	11·8	20·8	10·2
	9—18	26·1	12·7	25·7	10·6
	18—27	26·1	11·8	25·8	10·9
	27—36	26·7	13·4	25·0	12·5
	36—45	26·9	13·1	26·8	11·4
	45—54	27·0	14·3	27·5	14·3
	54—63	28·2	14·8	29·2	14·9
	63—72	31·3	17·4	30·1	16·3
Red	0—9	18·9	8·0	14·8	7·3
	9—18	23·9	10·5	20·9	8·0
	18—27	21·4	7·8	21·4	8·6
	27—36	24·0	8·8	20·7	9·1
	36—45	24·7	9·4	23·6	7·6
	45—54	25·3	10·9	26·2	9·8
	54—63	28·3	12·6	26·1	9·9
	63—72	30·6	14·5	31·2	12·7

Table V shows that the black soils are base-saturated to a greater extent than the red ones. The data in this table also show that the black soil contains nearly twice the quantity of exchangeable bases as compared to red soils.

TABLE V

p*H*, *exchangeable bases and percentages base saturation*

Colour of soil profile	Depth (in.)	*p*H*	M. eq. of total exchangeable bases present in soils, corrected for carbonate content†	M. eq. of base taken up by 100 gm. of soil‡	Per cent base-saturation $\frac{X}{Y} \times 100$
Black	9—18	6·0	13·9	23·1	60
	27—36	6·2	13·3	21·1	62
	45—54	7·0	14·3	22·4	64
	63—72	7·2	16·0	14·0	114
Red	9—18	5·2	7·0	13·7	51
	27—36	5·8	8·5	14·1	60
	45—54	6·2	8·0	13·5	59
	63—72	6·2	9·3	17·0	55

* Determined by Kuhn's barium sulphate method

† Determined by Rice William's method [1929]

‡ Determined by Schofield's method [1933]

SUMMARY AND CONCLUSIONS

1. A review of the existing literature dealing with the contrasted nature of tropical black and red soils has been made.

2. Physico-chemical properties of two contrasted soil profiles, red and black, occurring in close localities in Domira Bay in the Nyasaland Protectorate, have been compared.

3. Clay fractions from the red and black soils have approximately the same SiO_2/Al_2O_3 and $SiO_2/(Al_2O_3+Fe_2O_3)$ ratios. If, however, we consider soil samples from equivalent layers of the profile the red clay seems to possess a somewhat lower ratio than the black.

4. Red clay fractions contain more free iron oxide and free alumina than the black, as given by Truog's treatment. Also the black clay fraction contains more free silica than the red.

5. The percentage of organic carbon of the black soil of Domira Bay was somewhat higher than that of the equivalent layer of red, but not enough to

cause the enormous difference in colour of the two soil types. The C/N ratios of the black soils were uniformly higher than those for the red, suggesting that the proportion of protein matter was higher in the red soil than in the black. The organic matter of the black soil appeared to be more readily oxidizable than that of the red.

6. The buffer curves of black soils are more flattened than those of the red, indicating that the former are more active.

7. The black soils have higher moisture equivalents and higher imbibitional moisture capacities than the red soils, although the two soil types have nearly the same clay contents.

8. The black soils are base-saturated to a greater extent than the red ones. The data also show that the black soil contains nearly twice the quantity of exchangeable bases as compared to red soils.

REFERENCES

Annett, H. E. (1910). *Mem. Dept. Agric. Ind.* (*Chem. Ser.*) **1**, No. 9
Bal, D. V. (1935). *Trans. Third Internat. Cong. Soil Sci.* **3**, 155
Basu, J. K. (1939). *Ind. Soc. Soil Sci. Bull. No.* **2**, 8
Basu, J. K. and Sirur, S. S. (1938). *Ind. J. Agric. Sci.* **8**, 637—97
Hardy, F. (1931). *J. Agric. Sci.* **21**, 150—66
Harrison, W. H. and Ramaswami Sivan, M. R. (1912). *Mem. Dept. Agric. Ind.* (*Chem. Ser.*) **2**, No. 5
Keen, B. A. and Raczkowski, H. (1921). *J. Agric. Sci.* **11**, 441—9
Kenchington, F. E. (1935). *J. South-Eastern Agric. Coll. Wye* **36**, 176—80
Marchand, B. De. C. S. (1924). *S. Afric. J. Sci.* **21**, 162—81
Martin, F. J. and Doyne, H. C. (1927). *J. Agric. Sci.* **17**, 530—47
Maufe, H. B. (1928). *S. Afric. J. Sci.* **25**, 156—67
Raychaudhuri, S. P. (1937). *Science and Culture* **3**, 69—74
Raychaudhuri, S. P. and Nandi Mazumdar, A. B. (1939). *Ind. Soc. Soil Sci. Bull. No.* **2**, 34—60
——————————— (1940). *Ind. J. Agric. Sci.* **10**, 62—81
Raychaudhuri, S. P. and Sulaiman, M. (1940). *Ind. J. Agric. Sci.* **10**, 158—63
Russell, E. W. and Gupta, R. S. (1934). *J. Agric. Sci.* **24**, 315—25
Schofield, R. K. (1933). *J. Agric. Sci.* **23**, 252—4
Sen, A. T. (1939). *Ind. Soc. Soil Sci. Bull. No.* **2**, 9—13
Shantz, S. L. and Marbut, C. F. (1923). *The vegetation and soils of Africa* : New York
Theron, J. J. and Niekerk, P. le R. Van (1934). *S. Afric. J. Sci.* **31**, 320—46
Truog, E. and Drosdoff, M. (1935). *Trans. Third Internat. Cong. Soil Sci.* **1**, 92—5
Van der Merwe, C. R. (1935). *Trans. Third Internat. Cong. Soil Sci.* **1**, 302
Viswa Nath, B. (1939). *Ind. Soc. Soil Sci. Bull. No.* **2**, 4—7
Walkley, A. (1935). *J. Agric. Sci.* **25**, 598—609
Williams, Rice (1929). *J. Agric. Sci.* **19**, 589—99

STUDIES ON THE PARASITISM OF *COLLETOTRICHUM INDICUM* DAST. *

BY

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(With four text-figures)

A SEEDLING blight and boll-rot of *Gossypium herbaceum* (Uppam) has been observed at the Central Agricultural Station, Coimbatore, since 1925 [Sundararaman, 1926-1931]. The disease is confined to that species alone and is influenced to a large extent by seasonal conditions. In 1930 a survey of the cotton tracts of the Madras province showed that the disease is prevalent in Sivakasi (Ramnad district) also. Dastur [1934] has recorded a similar disease from the Central Provinces, which he describes as ' anthracnose ' occurring on *Gossypium arboreum* (types Verum, Roseum and Bani) and has named the parasite *Colletotrichum indicum*. The term 'anthracnose' has been used earlier in cotton pathological literature to denote another disease which resembles this to some extent but is caused by a different fungus. Such being the case, it may be advisable to give a different name to this disease in order to remove misconceptions. For instance in the *Review of Applied Mycology* [1937 ; 1939] while reviewing Dastur's administration report it is stated that ' anthracnose (*Glomerella gossypii*) caused severe infection of cotton '. The parasite referred to by Dastur is different from *Glomerella gossypii*. The mistake is presumably due to the use of the term anthracnose for the disease in India.

During the course of studies on different species of *Colletotrichum* occurring in South India it was considered desirable to obtain a culture of *C. indicum* from Mr Dastur for purposes of comparison. Since no culture was available with him he kindly sent diseased bolls and the fungus was brought into pure culture from these. Attention was first directed to find out the parasitism of this strain under local conditions and with this end in view several infection experiments were carried out and the results are recorded in this paper.

MATERIALS AND METHODS

The seeds of the varieties and species of cotton used in these experiments were kindly supplied by the Cotton Specialist, Coimbatore. These were sown in pots after delinting with concentrated sulphuric acid, except where otherwise stated. The pots containing seedlings were kept after inoculation inside glazed cages with a layer of moist sand at the bottom. The cages were kept humid by spraying with water once a day. The plants were inoculated by placing bits of fungus culture at the collar region or by spraying a suspension of spores by an atomizer on the cotyledons. The bolls were inoculated after surface-sterilization with 0·1 per cent mercuric chloride solution and kept inside moist chambers.

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INFECTION EXPERIMENTS

The first set of infection experiments was conducted on eight days' old seedlings of *Gossypium herbaceum* (H_1) and *G. arboreum* (K_1). In both the species all the inoculated seedlings succumbed. Brown lesions with water-soaked margins were formed at the collar region on the inoculated side. Later, these regions exhibited shrinkage of the tissues and the seedlings fell over. By this time the entire collar region had become blackish brown. Water-soaked spots, which later turned brown, developed on the cotyledons also. In the course of a week the seedlings had rotted down, cotyledons and hypocotyl included. On the surface of hypocotyl and cotyledons acervuli of the fungus had formed. The controls were quite healthy.

Dastur [1934] mentions that seedlings with a woody stem have not always been successfully inoculated except through wounds and that even this was not successful with plants having a well-developed woody stem. To find out the age up to which successful inoculation was possible, 20 seedlings each of the two species of cotton of varying ages were inoculated at the collar and the results are recorded in Table I.

TABLE I

Results of inoculation of seedlings of varying ages

Age of seedlings (days)	Inoculated		Control	
	H_1	K_1	H_1	K_1
4	All infected	All infected	All healthy	All healthy
8	,,	,,	,,	,,
12	,,	,,	,,	,,
16	,,	,,	,,	,,
21	,,	,,	,,	,,
27	All healthy	All healthy	,,	,,
32	,,	,,	,,	,,

Three weeks' old seedlings are readily infected. K_1 seedlings 35 days' old were inoculated after wounding the collar. There was brown discolouration of the collar but excepting for a surface crack the plants grew up healthy. Thus seedlings are liable to be infected only up to four weeks and if they escape infection for a month they are not affected by seedling blight.

The anthracnose of cotton in America has been known to be carried from year to year by the presence of the mycelium inside the seed-coat. Edgerton has noted spores of *Glomerella gossypii* on cotton seeds which were apparently healthy. Barre has shown that spores and hypahe of the same fungus remain on stalks and bolls in the field for over a year [Brown, 1938]. Both Sundararaman and Dastur have shown that in the Indian disease also the seeds may carry infection in the lint or seed-coat. Inoculation experiments were started to find out whether infection by *Colletotrichum indicum* can take place by spores carried on the surface of the seeds and through soil as with the anthracnose in America.

Healthy (fuzzy) seeds of *G. herbaceum* (H_1) were divided into two lots of 100 each. One lot was placed in a beaker containing a spore suspension and the other in a beaker of distilled water. They were separately kept under an air pump for 10 minutes after which they were sown in pots containing sterilized soil. In the inoculated series only 14 germinated and all these succumbed in the course of 10 days, while in the control pots 62 seeds germinated and all remained healthy.

The experiment was repeated using delinted seeds instead of fuzzy ones. In the inoculated set 32 per cent germination took place, while in the control there was 75 per cent germination. All the seedlings in the inoculated series were killed in six days while the controls were all healthy.

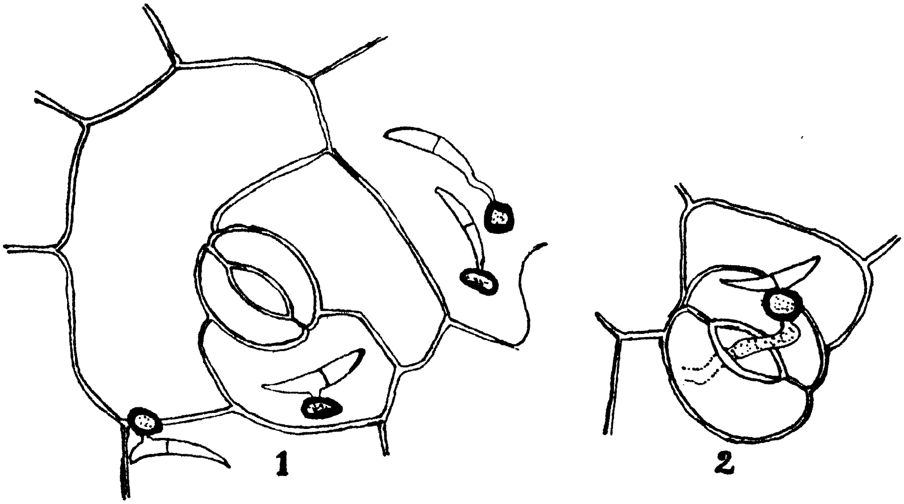
Various types of infection could be noticed in these experiments. In most of the seeds that had not germinated (in the inoculated series) the testa had burst at the micropylar end, but there was no further progress, the embryo having turned brown. Acervuli had formed on the testa and embryo. In some the radicle had pushed out, but the seedlings were affected before the hypocotyl had come above ground or the cotyledons had freed from the seed-coat. In others the cotyledons had unfolded but had brown spots which extended and finally involved the entire seedling. In still others the cotyledons were free, but the collar was infected and the seedlings died. Thus the experiments bring out the fact that the disease can be transmitted through spores on the surface of the seed and two phases in the expression of infection—the pre-emergence phase and the post-emergence phase—are evident.

For soil infection experiments, 20 pots were filled with garden soil and autoclaved for two hours at 120°C. The soil in 10 of the pots was mixed with culture of the fungus grown on sand and corn-meal medium, while in the other 10 pots sterile medium was added. Delinted seeds of H_1 cotton were sown in all the pots at the rate of 10 seeds for each pot. In the course of a week 68 per cent germinated in the infected pots, while there was 96 per cent germination in the control pots ; but all the seedlings in the former succumbed to the disease, while all remained free from disease in the latter. This clearly shows that infection can take place from the soil also.

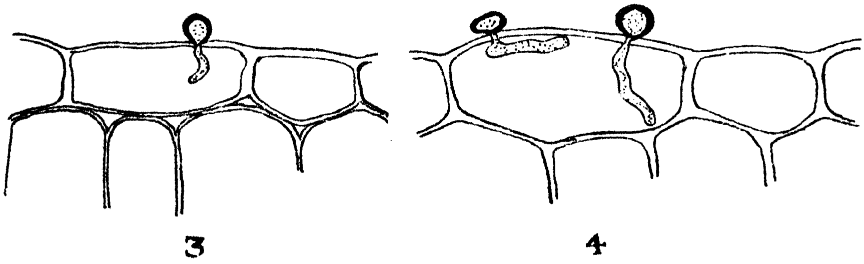
In another series the soil was mixed well with diseased seedlings and a fortnight later seeds were sown. In the control, healthy seedlings were cut up and mixed with the soil. All the seedlings in the former pots died in 10 days, while those in the control pots were healthy, showing thereby that the presence of diseased material in the soil is a source of danger.

ENTRANCE OF THE FUNGUS INTO THE HOST

The method of penetration by the fungus into the host plant was investigated. Seedlings were infected by placing suspensions of spores on cotyledons and collar region and then covered with bell-jar for 36 hours, after which the bell-jar was removed. Sections (hand and microtome) were taken at intervals to observe the entry and spread of the fungus in the tissues. On the cotyledons discolouration was noticed at the inoculated spot in 18 hours and well-defined brown spots appeared in 40 hours. In four days the spots had become quite brown and increased in size. After 18 hours small pieces of the epidermal tissue of the cotyledon were mounted in lactophenol and chloral hydrate (as described by Riker and Riker [1936]). It was found that the spores had germinated, a septum had formed in the middle of each spore, and appressoria had been produced either from the end of the germ tube or at the tip or side of the spore itself (Fig. 1). In a few, germ tubes had grown out of the appressoria and entered through the stomata (Fig. 2). In many others though appressoria were near the stomata there was no sign of penetration through them. Sections showed a shrinkage of the epidermal cells and from certain appressoria penetration hyphae had pierced through the outer epidermal wall and entered the epidermal cell (Figs. 3 and 4). After 42 hours inter-cellular hyphae were noticed in the mesophyll region, the cells were shrunk and some of the palisade cells had turned yellowish brown. In still later stages the hyphae were intra-cellular also, the cells had very much shrunk and lost the green colour.



FIGS. 1, 2. Surface view of epidermis of cotyledon showing germination of spores and entrance through stoma (× 500)



FIGS. 3, 4. Section of portion of cotyledon showing penetration through epidermis (× 500)

Sections of the hypocotyl taken after 18 hours showed that the epidermal cells had shrunk and turned brown and numerous appressoria had formed on the surface. After 42 hours shrinkage and discolouration had extended to two layers of sub-epidermal cells. Intra-cellular hyphae were not in evidence at this stage. Longitudinal sections revealed that in 18 hours spores had germinated, appressoria formed and penetration of the epidermal cells had taken place. In 42 hours the hyphae had developed inter-cellularly to a depth of two to three layers of cells, but they had extended more in length. In four days penetration had progressed throughout the cortex and intra-cellular hyphae were also formed. By this time the cells had shrunk and turned brown. Evidence is lacking to show that the cells are killed in advance of the mycelium. The quicker longitudinal spread of the mycelium must be responsible for the rapid extension of the lesions in length.

VARIETAL SUSCEPTIBILITY

The Coimbatore isolates of *Colletotrichum* in 1925-30 had a restricted parasitism, being confined to *G. herbaceum* (Uppam). Dastur [1934] has recorded the parasitism of the Nagpur strain on G. *arboreum* (Roseum, Verum and Bani). To find out whether other species and varieties of cotton and other host plants of *Colletotrichum* species are susceptible, infection experiments with the Nagpur isolate were carried out on several indigenous and exotic types of cotton besides plants recorded as hosts for *Colletotrichum* spp. The seedlings were eight to ten days' old and at least 30 seedlings were infected in each case, except in *G. stocksii*, *G. Davidsonii*, *G. Armourianum* and *G. Harknessii* where owing to scarcity of seeds only five plants were inoculated. The results of the experiments are given in Table II.

TABLE II

Infection experiments with the Nagpur isolate on cotton and other host plants of Colletotrichum

Host plant 1	Part inoculated 2	Results 3
Gossypium herbaceum types—		
1 H_1	Seedling (collar) . .	All seedlings killed
2 H2919	,, . .	,,
3 Dharwar 1 . . .	,, . .	,,
4 Kumpta wilt-resistant .	,, . .	,,
5 Jayawant . . .	,, . .	,,
G. arboreum types—		
1 K_1	,, . .	,,
2 Sanguineum . . .	,, . .	,,
3 Bani 306 . . .	,, . .	,,
4 Cocanadas 171 . .	,, . .	,,
5 N 14	,, . .	,,
6 Roseum	,, . .	,,
7 Poonam	,, . .	,,
8 Tellapathi . . .	,, . .	,,
9 Parbhani 710 . . .	,, . .	,,

TABLE II—*contd.*

Host plant 1	Part inoculated 2	Results 3
10 Verum 434	Seedling (collar)	All seedlings killed
11 Nadam	,,	,,
12 Burma C 19	,,	,,
G. hirsutum types—		
1 Co 2	,,	All healthy. No infection
2 Bourbon	,,	,,
3 Moco	,,	,,
G. Stocksii	,,	The collar affected, lesions formed but seedlings got over the attack
G. Davidsonii	,,	All healthy. No infection
G. barbadense types—		
1 Sea Island	,,	,,
2 Quebra	,,	,,
3 Verdao	,,	,,
G. Armourianum	,,	,,
G. Harknessii	,,	,,
G. arboreum × *G. barbadense* (back-crossed with *barbadense*)	,,	6 seedlings out of 28 took infection and died. Others remained healthy
Hibiscus esculentus	,,	No infection
Allium cepa (young plants)	,,	,,
Brassica oleracea var. *capitata*	Leaves and collar of seedlings	,,
,, var. *caulorapa*	,, ,,	,,
Capsicum annuum	,, ,,	,,
	Green fruits (unwounded)	,,
	,, (wounded)	Fruits rotted, acervuli formed on pericarp
Aristolochia bracteata	Leaves	Spots developed on the leaves
Zingiber officinale	Leaves (unwounded)	No infection
	,, (wounded)	Small brown spots round the inoculated portion. No extension

Suitable controls were kept in all cases and these remained healthy throughout.

It can be seen from Table II that the Nagpur isolate is capable of infecting several of the indigenous types of cotton in the seedling stage. In *G. Stocksii* which is a wild indigenous type the spread of infection is slow and actual death of seedlings is not noticed as in other cultivated types. The exotic types which include both wild and cultivated American cottons are not infected. The hybrid between the Asiatic and Amercian cottons shows about 22 per cent infection.

Dastur [1934] has found that bolls of *G. arboreum* (Verum, Bani and Roseum) are liable to be affected by this fungus, while Sundararaman has observed boll-rot of *G. herbaceum* (Uppam) alone. The parasitism of the isolate from the Nagpur material was tested on the bolls of some of the available types of cotton and the results are recorded in Table III.

TABLE III

*Parasitism *of the Nagpur isolate on bolls*

	Inoculated		Control	
	Unwounded	Wounded	Unwounded	Wounded
G. herbaceum—				
1 H_1 . . .	7/10	10/10	0/10	0/10
2 H 2919 . .	1/9	5/10	"	"
3 Dharwar II .	0/8	4/6	0/6	0/6
G. arboreum—				
1 K_1 . . .	0/10	0/10	0/10	0/10
2 Cocanadas 171 .	6/9	8/10	"	"
3 Roseum . .	0/10	8/10	"	"
4 Verum 434	"	0/10	"	"
5 Nadam . .	"	5/10	"	"
6 Cernuum . .	"	No external sign of infection but lint discoloured in inoculated lock in 4/10	"	"
7 Abu Haneira .	0/8	4/8	"	"
8 Nanking White .	3/9	10/10	"	"
9 Arboreum Vedasanthur	0/5	2/5	0/5	0/5
G. hirsutum—				
Co 2 . . .	0/10	0/10	0/10	0/10

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*The denominator gives the number of bolls used in the experiment and the numerator those that were infected.

The parasitism on the bolls is more restricted. All indigenous types are not attacked and wounded bolls are more readily infected than unwounded ones. The exotic type did not take infection.

DISCUSSION

Colletotrichum indicum Dast. is capable of causing seedling blight of most of the cultivated indigenous cottons. Heavy casualties may be caused according to the severity of infection. Besides bringing about the death of seedlings, the germination of seeds is prevented and thus a number gaps result in the field. But the susceptible stage is limited to a short period and if the seedlings can escape infection for four weeks no further damage is possible. This disease resembles to a large extent the American anthracnose of cotton. The spread of infection is also on similar lines. The fungus may be present inside the seed-coat of some seeds and this is quite possible because the bolls are infected. Besides this, the spores that may be present on the surface are also capable of infecting seedlings. The fungus may persist in the soil and help in the continuance of the disease. *Colletotrichum indicum* is capable of causing spots on the leaves of *Aristolochia bracteata*, and this plant is a common weed in black cotton soils. The ability of this fungus to parasitise bolls is restricted to some of the indigenous types belonging to *G. herbaceum* and *G. arboreum* groups.

Susceptibility to this fungus is confined to the indigenous (Asiatic) species and varieties of cotton. The American types are not infected. This is interesting, especially since the latter are themselves subject to anthracnose caused by *Glomerella gossypii*. This immunity is probably due to their different genetic constitution. The hybrid between *arboreum* and *barbadense* back-crossed to *barbadense* showed about 22 per cent susceptibility, proving thereby that the non-infection of seedlings of American type is due to the difference in the genetic make up. The cultivated Asiatic types are very susceptible, but the wild type shows a certain degree of resistance. Among the American types both the cultivated types having 52 chromosomes and the wild ones with 26 chromosomes ($2n$) do not get infected. Several indigenous types appear to be resistant to the boll-rot phase of the disease. Wounded bolls more readily take infection in the susceptible varieties, and in nature it is quite a common feature to note insect punctures on the pericarp and these can serve as places of entry. The Nagpur isolate infects wounded *Capsicum* fruits under Coimbatore conditions.

To obviate the chances of confusion with the American ' anthracnose ' of cotton it is proposed that the Indian disease be designated ' seedling blight and boll-rot ', the name adopted by Sundararaman [1926], which is highly descriptive of the different phases of the disease. *Colletotrichum indicum* belongs to the falcate-spored group of the genus while the conidial form of *G. gossypii* is cylindrical and hence the two parasites are entirely different.

I am greatly indebted to Mr K. M. Thomas, Government Mycologist, for help and sustained interest in the work. My thanks are also due to Rao Bahadur V. Ramanatha Ayyar, Cotton Specialist for kindly supplying the seeds of different varieties of cotton and to Mr J. F. Dastur for readily sending diseased specimens of cotton bolls.

SUMMARY

Colletotrichum indicum Dast. was isolated from diseased cotton bolls obtained from Nagpur. This isolate readily infects the seedlings of all the indigenous types of cotton experimented with. Seedlings over four weeks old are not infected. After five weeks even wound infections are not successful. Cultivated and wild American cotton seedlings are immune. A hybrid between Asiatic and American cottons exhibited partial susceptibility. Bolls of only some indigenous varieties are infected.

The fungus is capable of infecting leaves of *Aristolochia bracteata* and wounded fruits of *Capsicum annuum*.

Infection is both seed-borne and soil-borne. Penetration into the cotyledons is through stomata and epidermal cell. The base of the hypocotyl is entered through the epidermal cell. The hyphae spread in the beginning of infection mainly inter-cellularly but later become intra-cellular also.

REFERENCES

Brown, H. B. (1938). '*Cotton*': McGraw Hill Book Co., pp. 326-9

Dastur, J. F. (1934). *Ind. J. Agric. Sci.* **4**, 100-20

——————— (1937). *C. P. Dept. Agric. Ann. Rep.* (*Rev. Appl. Mycol.* **16**, 232)

——————— (1939). *C. P. Dept. Agric. Ann. Rep.* (*Rev. Appl. Mycol.* **18**, 372)

Riker, A. J. and Riker, R. S. (1936). '*Introduction to research on plant diseases*'

Sundararaman, S. (1926-1931). *Madras Dept. Agric. Rept. Government Mycol.*, 1925-26 to 1930-31

PARASITES OF THE INSECT PESTS OF SUGARCANE IN THE PUNJAB

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I. Introduction

SUGARCANE in the Punjab is attacked by a number of insect pests, the most important of which are the Pyralid moths, *Scirpophaga nivella* Fab., *Argyria sticticraspis* Hampsn., and *Chilo trypetes* Bisset and the Fulgorid bug, *Pyrilla perpusilla* Wlk. Between them they destroy about 35 per cent of the crop annually, but in a year of heavy outbreak each may be responsible for destroying 67 per cent of the crop. These pests are attacked by a number of insect parasites, observations on which were taken up as early as 1921 [Husain, 1921-1938]. Since 1934 these parasites have been under closer and more intensive study at four different centres in the Punjab, viz. Sonepat Gurdaspur, Jullundur and Lyallpur, each centre being representative of the soil and climatic conditions under which sugarcane is grown in the Punjab. The data collected during the course of these investigations is presented in this article.

II. Species of parasites

Order Hymenoptera

1. *Family Scelionidae*

Teleonomus (Phanurus) beneficiens Zehnt.

Distribution.—This parasite is widely distributed in the Punjab.

Insect hosts.—It parasitizes the eggs of *Scirpophaga nivella* Fab. So far, it has not been found on the eggs of any other insect host in the Punjab.

Bionomics.—The female parasite inserts her ovipositor, through the hairy covering of the egg-cluster, into an egg of the host insect and lays an egg therein. In captivity, a female parasite laid a total of 20 eggs in different egg-clusters of the host insect. The parasitized egg always turns black in colour. Table I gives the percentage of parasitization of *Scirpophaga nivella* Fab. eggs during February-October at Jullundur.

It is seen from Table I that *T. beneficiens* Zehnt. is most active in April and in August-October when it completes its life-cycle in 10-12 days. During May-July, when the temperature in shade is 117°F. and humidity 14 per cent, it becomes scarce. Its activities during November-January, when the insect host is present only as a hibernating caterpillar, have not been ascertained so far.

TABLE I

Percentage of parasitization of S. nivella *Fab. eggs by* T. beneficiens *Zehnt. at Jullundur*

Month	Number of host eggs examined	Number of host eggs found parasitized	Percentage parasitization
February .	830	148	17·8
March .	961	181	19·9
April .	339	173	51·0
May .	1,385	24	1·7
June .	439	*Nil*	*Nil*
July .	1,606	53	3·3
August .	1,821	848	46·6
September	27	14	52·0
October .	1,401	961	68·6

2. *Family Chalcididae*

Trichogramma 2 spp.

Distribution.—These parasites are common throughout the Punjab.

Insect hosts.—Two species of *Trichogramma* (not yet specifically identified) have been bred out in the Punjab from the eggs of *Argyria sticticraspis* Hampsn., *Chilo zonellus* Swinh., *Sesamia uniformis* Dudgn., and *Emmalocera depresella* Swinh.

Bionomics.—*Trichogramma* spp. are active during March-October. The period of their greatest abundance, however, is September-October, when in certain years they may parasitize 90 per cent of the host eggs. One of these two species of *Trichogramma* completes its life-cycle in the eggs of *Argyria* in about six days at 90°-98°F.

Elasmus zehntneri Ferr.

Distribution.—This parasite has so far been reported from Jullundur, Lyallpur and Sonepat.

Insect host.—It parasitizes only the full-grown larvae of *Scirpophaga nivella* Fab.

Bionomics.—*E. zehntneri* Ferr. is most active during July-February. The female selects a mature caterpillar for oviposition, stings it into a state of torpidity and lays its eggs in a cluster besides it. On hatching, the parasite larvae feed on the body juices of the paralysed host caterpillar, and when full-fed, they pupate in the tunnel (in which the host caterpillar was feeding in the stem of sugarcane) without cocoons.

Rhaconotus scirpophagae Wilksn.

Distribution.—This parasite is common at Lyallpur, but rare at Jullundur and Sonepat.

Insect hosts.—It attacks the larvae of *Scirpophaga nivella* Fab., *Emmalocera depresella* Swinh. and *Chilo trypetes* Bisset.

Bionomics.—It is active during October-March when it parasitizes 1-2 per cent of the hibernating host larvae, particularly those of *Scirpophaga nivella* Fab.

Goryphus sp.

Distribution.—This parasite is common at Jullundur, Lyallpur and Sonepat and rare at Gurdaspur.

Insect hosts.—It attacks the larvae of *Scirpophaga nivella* Feb. and *Chilo trypetes* Bisset.

Bionomics.—It is active during July-February : in 1934-35 and 1935-36 it parasitized respectively 13 and 3·2 per cent of the larvae of *Scirpophaga* during this period at Jullundur.

Stenobracon (Glyptomorpha) desae Cam.

Distribution.—It is common at Lyallpur and Sonepat but rare at Jullundur. It has also been recorded at Jhelum.

Insect hosts.—It parasitizes the larvae of *Scirpophaga nivella* Fab., *Argyria sticticraspis* Hampsn., *Chilo trypetes* Bisset, *Emmalocera depresella* Swinh. and *Chilo zonellus*, and the pupae of *Scirpophaga nivella* Fab.

Bionomics.—It is active from July to September.

Harmoniae sp.

Distribution.—It is common at Gurdaspur and Lyallpur but rare at Jullundur.

Insect hosts.—It parasitizes the larvae of *Scirpophaga nivella* Fab. and *Schaenobius bipunctifer* Wlk. (Rice borer : Pyralidae : Lepidoptera).

Bionomics.—It is active from September to February.

Chelonus sp.

Distribution.—This parasite has so far been collected from Sargodha only.

Insect hosts.—It parasitizes the larvae of *Scirpophaga nivella* F. and *Emmalocera depresella* Swinh.

Bionomics.—It was collected from the larvae of *Scripophaga* in October and from those of *Emmalocera* in April.

3. *Family Encyrtidae*

Ooencyrtus papilionus Ashm.

Distribution.—This parasite is uniformly distributed in the Punjab.

Insect host.—It is a very important egg parasite of *Pyrilla perpusilla* Wlk.

Bionomics.—The parasite is scarce during April-June. It becomes active in July, but it reaches its peak during the period from September to December when, along with *Tetrastichus pyrillae* Craw., it may parasitize 79 per cent, with an average of 30 to 40 per cent, of *Pyrilla* eggs. There is considerable reduction in its numbers during January-March, when it is found in sugarcane trash.

The life-cycle of the parasite is completed in 10-64 days depending upon the season as is clear from Table II. The female lives for about five days during April-October and about 24 days during the cold weather. The highest number of eggs laid by a female in confinement was 30.

TABLE II

Duration of the life-cycle of Ooencyrtus papilionus *Ashm. at Lyallpur*

Date of oviposition by the adult parasite	Date of emergence of the adult parasite	Duration of life-cycle (in days)
21 Aug.	31 Aug.	10
4 Oct.	20 Oct.	16
3 Nov.	28 Nov. to 2 Dec. . . .	25—29
23 Nov.	26 Jan.	64

Ascogaster sp.

Distribution.—It has so far been collected from Lyallpur only.

Insect host.—It parasitizes the larvae of *Emmalocera depressella* Swinh.

Bionomics.—The bionomics of this parasite has not been studied so far. It was found active in June.

Dipterous tachinida

Distribution.—It occurs at Lyallpur but is rare.

Insect hosts.—It parasitizes the caterpillars of *Sesamia uniformis* Dudgn.

Bionomics.—It was collected in July.

4. *Family Eulophidae*

Tetrastichus pyrillae Craw.

Distribution.—This parasite is widely distributed in the Punjab.

Insect host.—It parasitizes the eggs of *Pyrilla perpusilla* Wlk.

Bionomics.—*T. pyrillae* Craw. is active throughout the year. Its life-cycle is completed in 11-23 days, depending upon the season, as is seen from Table III.

TABLE III

Duration of life-cycle of Tetrastichus pyrillae *Craw.*

Date of oviposition by the adult parasite	Date of emergence of the adult parasite	Duration of life-cycle (in days)
23 April	5 May	12
24 April	5 May	11
28 Sept.	9 Oct.	11
19 Oct.	5 Nov.	17
8 Nov.	1 Dec.	23

Seasonal abundance of the egg parasites of Pyrilla perpusilla *Wlk.*—Observations on the yearly fluctuation in the population of *Pyrilla* egg parasites were made during 1926-34 at Lyallpur and the results are given in Table IV.

TABLE IV

Yearly fluctuation in the population (expressed as percentage of parasitization) of Pyrilla *egg parasites* (O. papilionus *Ashm. and* T. pyrillae *Craw.) at Lyallpur*

Year	July	August	September	October	November	December
1926	5·7	13·9	49·3	40·9	29·7	5·8
1928	14·3	29·0	36·5	32·2	27·6	25·0
1929	..	..	13·3	24·0	24·5	9·3
1930	..	..	26·0	38·0	33·0	12·2
1931	..	19·0	27·0	52·0	79·0	36·0
1933	..	..	71·5	77·9	51·2	20·8
1934	..	28·0	46·0	47·6	42·0	..

It is seen from Table IV that the *Pyrilla* egg parasites are most active during September-November when they may parasitize 71·5 to 79 per cent of the host eggs. Table V gives the percentage of parasitization of *Pyrilla* eggs by *O. papilionus* and *T. pyrillae* Craw.

TABLE V

Percentage parasitization by the two Pyrilla *egg parasites during July-December*

Month and year	Number of eggs examined	Number of host eggs found parasitized	Parasitization percentage
July—			
1928 .	**929**	**132**	**14·2**
1932 .	**838**	**254**	**30·4**
1935 .	**1,913**	**2**	**0·1**
August—			
1934 .	**453**	**127**	**28**
1935 .	**2,926**	**1**	**0·03**
September—			
1932 .	**5,133**	**2,062**	**40**
1933 .	**2,012**	**1,439**	**71·5**
1934 .	**3,545**	**1,588**	**44·8**
1935 .	**5,021**	**2,065**	**41**

TABLE V—*contd.*

Month and year	Number of eggs examined	Number of host eggs found parasitized	Parasitization percentage
October—			
1932 .	2,811	1,405	50
1933 .	1,094	853	78·0
1934 .	256	119	46·4
1935 .	13,060	1,593	12·2
November—			
1932 .	3,507	2,454	70
1933 .	737	376	51·0
1934 .	256	119	46·4
1935 .	13,060	1,593	12·2
December—			
1932 .	875	429	49
1933 .	891	186	20·8
1935 .	29,443	5,257	17·9

Both these parasites are not very active during April-June and again during January-March when the percentage of parasitization is very low indeed ; of the 58,472 and 2,937,173 eggs examined during these two periods only 0·004 and 0·0006 per cent respectively were found parasitized by these two parasites.

The intensity of attack on the eggs of *Pyrilla* by the two parasites, *O. papilionus* Ashm. and *T. pyrillae* Craw., depends upon the location of the host eggs : the eggs laid exposed on the leaves are much more heavily parasitized (up to 77·9 per cent) than those laid hidden in between the leaf-sheath and the cane stem which never have more than 5 per cent parasitization.

Efficiency of Pyrilla *egg parasites in the fields.*—In order to study the efficiency of *Pyrilla* egg parasites the sugarcane crop growing in two separate blocks at the Sugarcane Research Station, Jullundur, was selected in 1935-36. The two selected blocks were about 550 ft. apart. In the beginning of August 1935, only 2 per cent of the *Pyrilla* egg-clusters were found parasitized in them.

In one block encouragement of the egg parasites was taken up while the other block was kept as control. In the treated block (about 2 acres) about 2,900 parasitized egg-clusters were placed in parasite-hibernating cages (specially designed for the purpose) which were distributed over the entire block.

Parasitization was at par (2 per cent) in both the blocks to begin with. During the fourth week of August, however, parasitization increased to 55 per cent in the block where parasites were encouraged but it was only 9 per cent in the control block.

5. *Family Drynidae*

Lestrodrynius pyrillae Kieff.

Distribution.—It has been recorded at Gurdaspur, Jullundur, Lyallpur and Sonepat.

Insect host.—It attacks the nymphs of *Pyrilla perpusilla* Wlk.

Bionomics.—This parasite remains active throughout the year excepting during the period from January to mid-March when it is mostly present as pupae. Its extent of parasitization depends upon the age of the host nymphs : first stage nymphs are usually not much parasitized, but second and fifth stage nymphs are comparatively more, while the third and fourth stage nymphs are most heavily parasitized.

A female parasite lays up to 42 eggs. Its life-cycle occupies 37-157 days as is clear from Table VI.

TABLE VI

Duration of life-cycle of L. pyrillae *Kieff.*

Date of oviposition by the female parasite	Date of emergence of the adult parasite	Duration of life-cycle (in days)
18 April	25 May	37
27 Aug.	3 Oct.	37
27 Oct.	2 April	157
29 Nov.	6 April	128
8 Dec.	10 April	123

The percentage of parasitization by this parasite was studied during 1930-36 when more than 42-5 thousands of nymphs were examined. (Each parasitized nymph was found to have 1-3 Drynid sacs.) The results for January-June 1931 and July-December 1930 only are presented in Table VII.

TABLE VII

Percentage of parasitization of the nymphs of Pyrilla by L. pyrillae *during different months of the year*

Time of the year	Locality	Percentage parasitization of *Pyrilla* nymphs
January . .	Jullundur .	0·2
	Lyallpur .	1·2
February .	Jullundur .	0·2
	Lyallpur .	0·3
March . .	Jullundur .	0·2
	Lyallpur .	0·2

TABLE VII—*contd.*

Time of the year	Locality	Percentage parasitization of *Pyrilla* nymphs
April . . .	Jullundur .	0·2
	Lyallpur ..	0·2
May . .	Jullundur .	0·2
	Lyallpur .	0·6
June . .	Jullundur .	0·2
	Lyallpur .	3·5
July . .	Jullundur .	1·5
	Lyallpur .	1·5
August . .	Jullundur .	1·6
	Lyallpur .	0·8
September .	Jullundur .	1·9
	Lyallpur .	2·1
October . .	Jullundur .	2·5
	Lyallpur .	3·2
November .	Jullundur .	3·1
	Lyallpur .	3·1
December .	Jullundur .	0·5
	Lyallpur .	0·2

It is seen from Table VII that though the parasite is present throughout the year, it is abundant during September-November only.

L. pyrillae Kieff. is hyperparasitized by *Cheiloneurus* sp. (Fam. Encyrtidae) which is usually active during November-March.

ORDER STREPSIPTERA

Pyrilloxenos compactus Pierce

Distribution.—This parasite was recorded in the Punjab for the first time in 1928. Subsequently it was found to be fairly abundant throughout the sugarcane-growing areas of the Punjab and has been actually collected from Gurdaspur, Jullundur, Lyallpur and Sonepat.

Insect hosts.—It parasitizes the nymphs and adults of *Pyrilla perpusilla* Wlk., but shows a decided preference for the adults.

Bionomics.—It is a parasite of sporadic occurrence. During the period (1928 to date) it has been under study it occurred in abundance in 1934 at Lyallpur and in 1935 at Sonepat while in other years it was scarce throughout the province.

The parasite remains active throughout the year. Table VIII gives the duration of the life-cycle of the male.

TABLE VIII

Duration of the life-cycle of the male P. compactus *Pierce*

Triungulinid hibernated in host	Adult male emerged	Duration of life-cycle (in days)
16 May	27-29 June	42—44
27 Sept.	5 Nov.	39

The parasite has about five generations in a year as follows : February, May, May-July, July-September, September-November, November-February.

Table IX gives the percentage of parasitization in 1934 at Lyallpur and in 1935 at Sonepat.

TABLE IX

Percentage of parasitization of P. perpusilla *adults and nymphs by* P. compactus *Pierce*

(Total number of nymphs examined—1977; total number of adults examined—791)

Period		Locality	Nymphs	Adults
May	1934	Lyallpur	. .	28·9
June	,,	,,	14·2	. .
July	,,	,,	71·0	18
August	,,	,,	18—32	11·49
November	,,	,,	9	22
December	,,	,,	0·5	7
February	1935	Sonepat	11	10
March	,,	,,	88	50
April	,,	,,	86	37
May	,,	,,	10	37
June	,,	,,	12	66
July	,,	,,	35	. .
August-November 1935		,,	0·07—2·6	1·1—2·3

III. SUMMARY

The insect pests of sugarcane in the Punjab are attacked by about 14 different kinds of parasites which have been under observation since 1921. Of these parasites the following require special mention.

Teleonomus beneficiens Zehnt. : This is a widely distributed parasite of the eggs of *Scirpophaga nivella* Fab. This parasite is most active in April and in August-October, when it parasitizes 5 and 45-68·5 per cent of the host eggs respectively.

Trichogramma spp. parasitize the eggs of *Argyria sticticraspis* Hmpsn., *Chilo zonellus* Swinh., *Sesamia uniformis* Dudgn. and *Emmalocera depressella* Swinh. These parasites are active during March-October when, in certain years, they may parasitize 90 per cent of the host eggs.

Ooencyrtus papilionus Ashm. and *Tetrastichus pyrillae* Craw. are the very important egg parasites of *Pyrilla perpusilla* Wlk. which are widely distributed in the Punjab. These parasites are most active during September-November when they may parasitize 71·5 to 79·0 per cent of the host eggs.

Other parasites are discussed under distribution, insect hosts and bionomics in this paper.

REFERENCES

Husain, M. A. (1921-38). *Ann. Repts. Ent. Govt. Punjab, Lyallpur* (for each year from 1921 to 1938)

Rahman, Khan A. and Ram Nath (1940). *Bull. Ent. Res.* (*London*) **31**, Part 2

PLANT QUARANTINE NOTIFICATIONS

INDIA

Notification No. F. 30-7/37, dated June 7, 1940

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

I. In the said Order—

(*i*) (*a*) paragraph 5 shall be re-numbered as sub-paragraph (1) of that paragraph ; (*b*) in that paragraph as so re-numbered, the words ' in the form prescribed in the Third Schedule ' shall be omitted ; (*c*) to that paragraph as so re-numbered the following sub-paragraph shall be added, namely :—

' (2) The certificate shall be in the form prescribed in the Third Schedule or in a form as near thereto as may be and supplying all the information called for in that form '.

(*ii*) in paragraph 7 for the words ' *Fomes semitostus* ' the words ' *Fomes lignosus* ' shall be substituted, and for the words ' *Fusicladium macrosporum* ' the words ' *Dothidella ulei* (=*Melanopsammopsis ulei*=*Fusicladium macrosporum*) ' shall be substituted,

(*iii*) in paragraph 8A for the words ' the *Mal de Secco Deuterophoma tracheiphila* ' the words ' *Mal Secco* caused by *Deuterophoma tracheiphila* ' shall be substituted,

(*iv*) in sub-paragraph (2) of paragraph 9 for the word ' aleurodes ' the word ' whiteflies ' shall be substituted and for the words ' *Theilaviopsis paradoxa* ' the words ' *Ceratostomella paradoxa* or *Theilaviopsis paradoxa* ' shall be substituted.

II. In the Schedules annexed to the said Order—

(*i*) for the First Schedule the following Schedule shall be substituted, namely :—

' *FIRST SCHEDULE* [Paragraph 1 (*i*)]

Rule 5—General health certificate
Rule 6 (*b*)—Potatoes
Rule 7—Rubber plants
Rule 8A—Lemon plants and other citrus plants
Rule 8B—Unmanufactured tobacco
Rule 9—Sugarcane, etc.

Paragraph 1	Country of origin 2	Authority 3
5, 6 (*b*), 7, 8A & B and 9	Angola . . .	The Director, Laboratory of Plant Pathology and Agricultural Entomology, Directorate of Agricultural and Commercial Services, LUANDA
	Argentine . .	The Ministry of Agriculture

Paragraph 1	Country of origin 2	Authority 3
5, 6 (*b*), 7, 8A & B and 9—*contd.*	Australia . .	Chief Quarantine Officer for Plants
	Belgian Congo .	The Department of Agriculture, Industry and Commerce
	Belgium . .	The Department of Agriculture (Phytopathological Service)
	Bermuda . .	The Department of Agriculture
	Brazil . . .	Service de Vigilancia Sanitaria Begetal
	British Guiana .	The Department of Science and Agriculture
	British Honduras .	The Department of Agriculture
	Burma . . .	The Department of Agriculture
	Canada . . .	Dominion Department of Agriculture
	Ceylon . . .	The Department of Agriculture
	China . . .	Plant Quarantine Service, Ministry of Economic Affairs, Chungking, SZECHWAN
	Cyprus . . .	The Department of Agriculture
	Denmark . .	The Ministry of Agriculture
	Dutch Indies . .	The Department of Agriculture, Industries and Commerce
	Egypt . . .	The Ministry of Agriculture
	Eire . . .	The Department of Agriculture
	France . . .	The Ministry of Agriculture
	Gambia . .	The Department of Agriculture
	Germany . .	The Department of Agriculture
	Gold Coast . .	The Department of Agriculture
	Great Britain and Northern Ireland	The Ministry of Agriculture and Fisheries, England The Ministry of Agriculture, Northern Ireland The Department of Agriculture, Scotland
	Greece . . .	The Ministry of Agriculture

Paragraph 1	Country of origin 2	Authority 3
5, 6 (*b*), 7, 8A & B and 9—*contd.*	Holland . .	The Department of Agriculture
	Hong Kong . .	The Superintendent of Botanical and Forestry Department
	Hungary . .	Kingdom of Hungary Official Phytosanitary Service (Magyar Kiralysag Hivatalos Novenyegeszsegugyi Szolgalat)
	Iraq . . .	The Director of Agriculture, Baghdad
	Italy . . .	The Ministry of Agriculture
	Jamaica . .	The Director, Department of Science and Agriculture, Kingston, Jamaica
	Japan (including Formosa)	The Ministry of Agriculture and Forestry
	Kenya Colony .	The Department of Agriculture
	Malaya Peninsula .	The Department of Agriculture, Straits Settlements and Federated Malay States
	Malta . . .	The Department of Agriculture
	Mauritius . .	The Department of Agriculture
	Mozambique . .	Chief, Division of Entomology Technical Service for Agriculture, Lourenco Marques
	New Zealand . .	The Department of Agriculture, Wellington
	Nigeria . . .	The Department of Agriculture
	Norway . .	The Norwegian Board of Agriculture
	Nyasaland . .	The Department of Agriculture
	Palestine . .	The Department of Agriculture and Fisheries
	Philippine Islands .	The Bureau of Agriculture
	Portugal (including Azores and Madeira)*	The Chief Plant Pathologist, Department of Phytopathological Services, Ministry of Agriculture, Portugal

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* The Phytopathological Services in Azores and Madeira are under the personal supervision of the Chief Plant Pathologist. Fumigation Chambers are available in Madeira at which plants may be fumigated on request of exporters. When there is doubt as to the health of plant exports, the material is sent from Azores and Madeira to the Chief Plant Pathologist for inspection and, if feasilble, certification.

Paragraph 1	Country of origin 2	Authority 3
5, 6 (*b*), 7, 8A & B and 9—*contd.*	Rhodesia (Northern)	The Director of Agriculture, Mazabuka
	Rhodesia (Southern)	The Secretary for Agriculture and Lands, Salisbury
	Sierra Leone . .	The Department of Agriculture
	South Africa . .	The Union of South Africa, Department of Agriculture
	Spain . . .	Phytopathological Inspection Service appointed by the Director-General of Agriculture
	Straits Settlements	The Director of Agriculture or Director of Gardens
	Sweden . .	The Ministry of Agriculture
	Tanganyika . .	The Department of Agriculture
	Trinidad and Tobago	The Department of Agriculture
	Uganda Protectorate	The Department of Agriculture
	United States of America	The Department of Agriculture
	Windward and Leeward Islands	Advisory Department of Agriculture at the Imperial College of Tropical Agriculture, Trinidad
	Zanzibar . .	The Department of Agriculture
	**Other countries*	
	Algeria . . .	The Ministry or Department of Agriculture of the countries concerned
	Bulgaria . .	
	Costa Rica . .	
	Eritrea . .	
	Estonia . .	
	Finland . .	

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* When a Customs Officer receives a certificate required by the rules from any country not specified by name in any part of the schedule which relates to such certificate, he shall after passing the consignment forward the certificate to the Government of India, Education, Health and Lands Department, for information.

Paragraph 1	Country of origin 2	Authority 3
5, 6 (*b*), 7, 8A & B and 9—*contd.*	French Equatorial Africa	The Ministry or Department of Agriculture of the countries concerned
	French West Africa	
	Indo-China	
	Iran	
	Italian Somaliland	
	Lithuania	
	Luxemburg	
	Mexico	
	Morocco	
	Switzerland	
	Tunis	
	Turkey	
	Union of Soviet Socialist Republics	
	Uruguay	
	Yugoslavia	

Additional authorities empowered to certify against the diseases specified in paragraphs 6 (b), 7, 8A & B and 9

7	Burma	Mr L. P. Khanna, M.Sc., Lecturer in Biology, University College, Rangoon
8A	Burma	Mr L. P. Khanna, M.Sc., Lecturer in Biology, University College, Rangoon
	Italy	Royal Italian Phytopathological Institute
	Rhodesia (Northern)	The Department of Agriculture
	Rhodesia (Southern)	The Department of Agriculture

Paragraph 1	Country of origin 2	Authority 3
Additional authorities empowered to certify against the diseases specified in paragraphs 6 (b), 7, 8A & B and 9—contd.		
9	Australia (Queensland)	Department of Agriculture and Stock
	Burma . . .	Mr L. P. Khanna, M.Sc., Lecturer in Biology, University College, Rangoon
	Jamaica . .	The Department of Science and Agriculture
	West Indies . .	The Imperial College of Tropical Agriculture, St Augustine, Trinidad

(*ii*) in the form of Certificate set forth in the Third Schedule for the words and brackets ' the plant(s), living plant(s) or plant products ' the following shall be substituted, namely :—

' the plant(s), living plant(s) or plant products

a representative sample of the plant(s), living plant(s) or plant products '.

Notification No. F. 43-20/40-A., dated July 17, 1940

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendment shall be made in the Order published with the Government of India, Department of Education, Health and Lands, Notification No. F. 320/35-A., dated the 20th July 1936, namely :—

In the second proviso to paragraph 4 of the said Order for the letters and words ' Dr L. S. Doraswami ' and ' Dr Doraswami ' the letters and words ' Mr H. C. Javaraya ' and ' Mr Javaraya ' shall be substituted respectively.

Notification No. F. 43-15/40-A., dated August 14, 1940

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendment shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

In paragraph 8B of the said Order, after the words ' British India ', the words ' except from Burma ' shall be inserted.

Notification No. 46-29/38-A., dated October 9, 1940

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendment shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

In clause (*iii*) of paragraph 1 of the said Order, for the word ' Rangoon ' the words ' Port Blair ' shall be substituted.

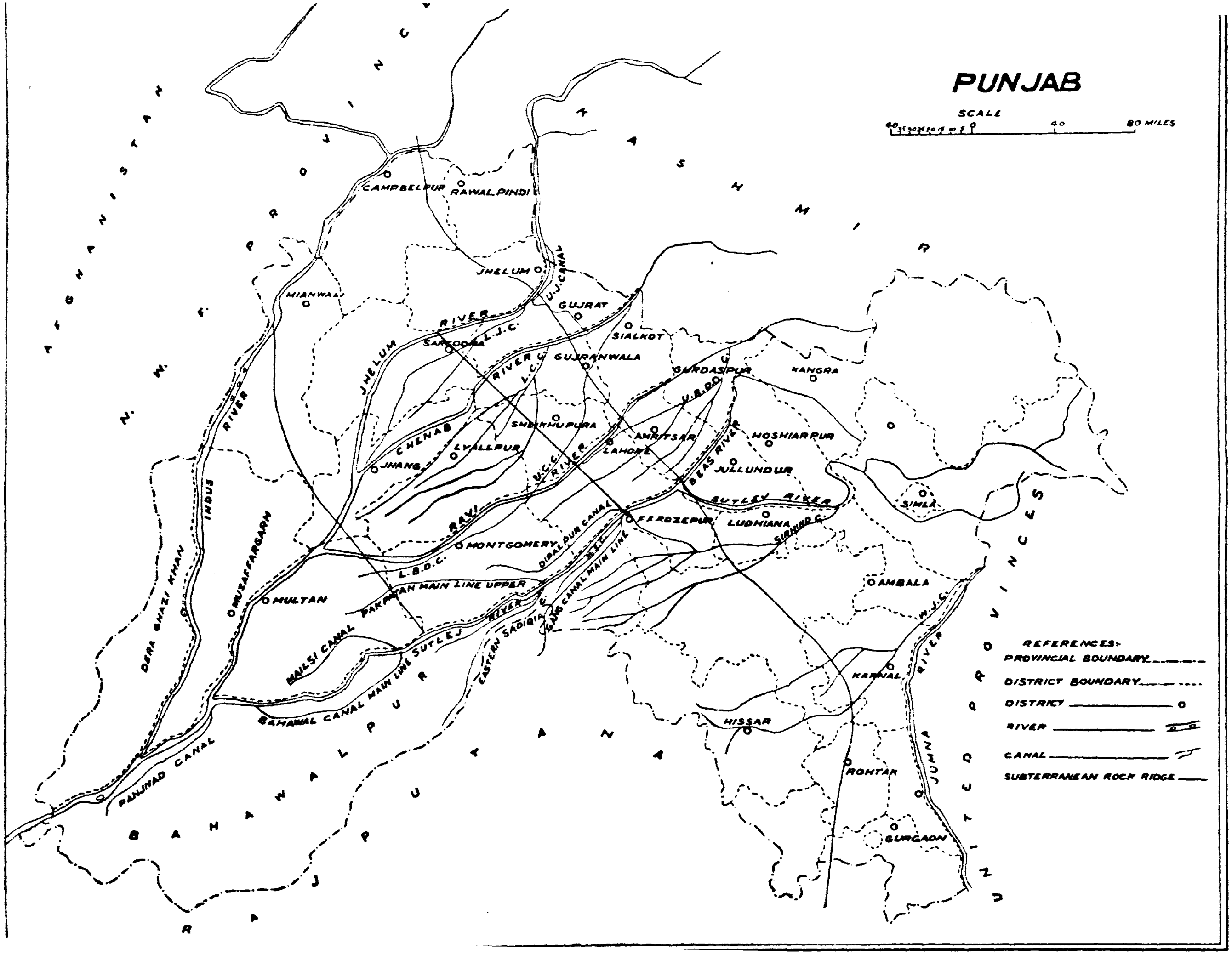
FOREIGN PLANT QUARANTINE REGULATIONS

UNITED STATES OF AMERICA

The following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research. New Delhi, for loan.

LIST OF UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE, SERVICE REGULATORY ANNOUNCEMENTS

1. *Quarantine and other official announcements*—
    - (*i*) Fruit and vegetable quarantine—modification of regulations
    - (*ii*) Pink bollworm quarantine—Administrative instructions
    - (*iii*) Coffee quarantine—Notice of Quarantine No. 73 on account of coffee pests
2. *Summaries of plant quarantine import restrictions*
   Republic of Paraguay-Curculio added to List of Declared Pests
3. *Service and Regulatory announcements*
   October-December 1939


PUNJAB
SCALE
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REFERENCES:-
PROVINCIAL BOUNDARY
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N. W. F. PROVINCE
KASHMIR
UNITED PROVINCES
BAHAWALPUR
RAJPUTANA
CAMPBELPUR
RAWALPINDI
JHELUM
U.J. CANAL
MIANWALI
GUJRAT
SIALKOT
JHELUM RIVER
L.J.C.
SARGODHA
GUJRANWALA
RIVER
L.C.C.
GURDASPUR
KANGRA
U.B.D.C.
SHEIKHUPURA
CHENAB
LYALLPUR
JHANG
AMRITSAR
LAHORE
U.C.C.
RIVER
BEAS RIVER
HOSHIARPUR
JULLUNDUR
SUTLEJ RIVER
SIMLA
RAVI
FIROZEPUR
LUDHIANA
SIRHIND C.
DIPALPUR CANAL
MONTGOMERY
L.B.D.C.
AMBALA
MULTAN
PAKPATAN MAIN LINE UPPER
B.I.C.
GANG CANAL MAIN LINE
MAILSI CANAL
SUTLEJ RIVER
EASTERN SADIQIA
MAIN LINE
BAHAWAL CANAL
KARNAL
W.J.C.
RIVER
HISSAR
ROHTAK
JUMNA
GURGAON
DERA GHAZI KHAN
INDUS
RIVER
MUZAFFARGARH
PANJNAD CANAL

ORIGINAL ARTICLES

SOME IRRIGATION PROBLEMS IN THE PUNJAB

BY

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(With Plate X and nine text-figures)

I. INTRODUCTION

IRRIGATION problems in the Punjab cover a very wide field which includes construction and maintenance of headworks, river training, maintenance of canals, the distribution and use of irrigation water with which are associated the waterlogging and the deterioration of land due to the accumulation of salts at the surface. Since about 40 per cent of the revenue of the province is derived directly from irrigation and a further 45 per cent is obtained indirectly, the financial aspect of irrigation is also of considerable importance and presents problems which require solution.

A brief description of the rivers and their associated irrigation systems will assist in the appreciation of the problems with which the Irrigation Department is faced. The word ' Punjab ' means the land of the Five Rivers, these being the Sutlej, the Beas, the Ravi, the Chenab and the Jhelum. With the exception of the Beas each of the rivers has an associated canal system or systems. The eastern boundary of the Punjab is the Jumna river from which the Western Jumna Canal system takes off. On the west, the Punjab is bounded by the Indus and the construction of a canal system to use the waters of the Indus to irrigate the desert areas between the Indus and the Chenab rivers has now commenced. During the winter the discharges in the rivers are low, the water being derived from seepage in their catchment areas. The sources of the Punjab rivers are situated in the high portions of the Himalayas. The supply of water in the rivers in the spring is, therefore, dependent upon the winter snowfall and the rate at which the snow melts. Generally, the rivers start rising in March and carry silt which is grey in colour and which has resulted from the physical weathering of the rocks in the higher ranges of the Himalayas. The monsoon usually breaks towards the end of June, and with the high rainfall in the low hills river supplies in summer are high and the silt carried by rivers changes from grey to red due to the erosion of the hills usually below 9,000 ft. in height.

A typical canal system in the Punjab consists of a barrage across the sandy bed of the river, the headworks of the canal, the main line, branches, distributaries and minors. The minors discharge into the watercourses, for the maintenance of which the zemindar is responsible. As the barrage is constructed on the sandy bed of the river, one of the main problems has been to design the work so that it will withstand the uplift pressures due to the water which it heads up. Until recently designs for barrages were based on Bligh's [1927] Creep theory. The work carried out at the Irrigation Research Institute and investigations of pressures on actual structures have shown that Bligh's basis for design is unsound. The subject of uplift pressures has been investigated experimentally and theoretically in the laboratory, and practical studies have been made in the field. The results of these studies have been embodied in a number of publications of the Irrigation Research Institute and have been collected in a publication of the Central Board of Irrigation [Khosla, Bose and McKenzie Taylor, 1936]. It is now possible to design a barrage which will be safe against uplift pressure and for which the maintenance costs will be low.

The practice in the Punjab is to construct a barrage in a dry portion of the river-bed. On completion of construction the river is diverted on to the barrage by closing the main channel with an earthen embankment. In recent years models of the river and barrage have been made in order to study the difficulties that will be encountered during the construction and diversion periods. These models have given valuable information and have resulted in considerable savings in the costs of construction.

The canal systems of the Punjab consist of two types which may be called ' irrigating ' and ' carrier '. In an irrigating canal system the whole of the water taken in at the head of the canal is used for the irrigation of crops in the culturable commanded area. The main purpose of a carrier canal is to transfer water from one river system to another in order that the supplies may be balanced and deficiencies in one river may be made good from the surplus in another. By means of these carrier canals, water is transferred from the Jhelum to the Chenab, from the Chenab to the Ravi, and now from the Ravi to the Sutlej. The construction of these carrier canals has enabled the most efficient use to be made of the whole of the water available in the Punjab rivers during the winter months.

The soils of the Punjab plains consist of alluvium which in some cases is covered by aeolian deposits. The soil generally contains from 10 to 15 per cent of clay and has an average depth of 10 ft. The soil crust overlies a sand in which the water-table is situated. The soil itself has generally an alkaline reaction due to the presence of sodium in the clay complex. Sodium salts are usually present in the soil crust and the control of their movement is one of the major problems of irrigation and agriculture. The soils usually have a high content of calcium carbonate which is sometimes present in the nodular form, locally called *kankar*. Wilsdon and Bose [1934] carried out a geodetic survey of certain portions of the plains and have shown that a subterranean rock ridge is present. This ridge is composed of rhyolite and it divides the Punjab into two areas, so far as its underground characteristics are concerned. The importance of this rock ridge in connection with the rise of water-table and waterlogging will be dealt with later.

The climate of the Punjab may be described as semi-arid. The major portion of the rainfall occurs in the period June to September, while winter rains, not exceeding one or two inches, occur in December and January. Precipitation decreases as the distance from the Himalayas increases. The rainfall in the foot-hills averages about 30 in. but a large part of the Punjab has rainfall of under 20 in. a year and in the driest portion the rainfall amounts to only 4 in. The irrigated area is situated in the rainfall belt below 20 in. The maximum temperature usually occurs in May and June and may be as high as 120°F. The minimum temperature occurs in January when two or three degrees of frost may be recorded. The seasons in the Punjab are known as *kharif* and *rabi*, the *kharif* season extending from April 15 to October 15 and the *rabi* from October 15 to April 15. In the *kharif* season the main crops are cotton, sugarcane, rice and maize. In the *rabi* season wheat is the principal crop though *toria* (*Brassica campestris*), gram, and barley are also grown. The *toria* crop presents a difficulty regarding the use of the available water towards the end of the *kharif* season since it is sown on *kharif* water and is matured on the *rabi* supplies.

II. CONSTRUCTION AND MAINTENANCE OF CANAL SYSTEMS

The main factors to be considered in the design of a canal system are the discharge in the river in winter and the slope available which determines the grade of silt which the channel can carry. The principal factor upon which the maintenance of a canal depends is the silt which enters the headworks and is distributed throughout the canal system. In the past attempts have been made to draw rules for design taking into account the type of silt expected to form the bed of the channel. The most notable of the earlier works on this subject is that of Kennedy [1896]. The Punjab canals have largely been designed according to the rules which he evolved. Lacey [1930] published a paper on stable channels in alluvium and introduced the silt factor. As a result of Lacey's paper the importance of silt in the design of a canal system was again brought to the fore. Lacey's equations have now been adopted for design in many provinces in India. During the past five years investigations have been in progress in the Punjab with the object of introducing a characteristic of silt into the equations for design. The bed silt of the Punjab canals usually lies between 0·075 mm. and 0·6 mm. in diameter. The silt-transporting power of water in a canal system is determined by the slope of the canal and its discharge. Material which is too coarse to be transported will be deposited on the beds of the channels. This deposition of silt on the bed may reduce the capacity of the channel which can only be restored by raising the banks. It may also induce the banks to scour with resultant breaches unless they are strengthened. Silt therefore is one of the main causes of the high cost of maintenance of some canal systems.

A series of 24 sites known to be in regime was selected on two canal systems. These sites have been under daily observation for the past five years. The usual hydraulic data have been collected and in addition a sample of the bed silt present in the canal at the sampling site was taken. The mean diameter of the particles composing the bed silt was determined by means of Vaidhianathan's [1933] siltometer. The results were examined by the methods of correlational analysis and a relationship between S, the slope, Q the discharge and m the mean diameter of the silt particles was established [Bose and Malhotra, 1939]. This relationship is as follows :—

$$S \times 10^3 = 2{\cdot}09 \quad \frac{m^{\cdot 86}}{Q^{\cdot 21}}$$

Since this formula has been derived by the study of regime sites of canal systems in the Punjab, its application was at first limited to these systems. Recently, however, it has been shown that it also applies to regime reaches of the Mississippi river and may be found of more general use than was originally indicated.

The formula has a number of important applications. If the mean diameter of the silt in suspension in the river at the site of a proposed headworks is known, it is now possible to determine whether with the designed discharge and the slope available a canal can be constructed which will be non-silting and non-scouring. If this silt is too coarse for the proposed canal then measures can be taken at the head to exclude or extract the harmful silt from the water entering a canal. For this purpose silt excluders and extractors have been added to the headworks of the Main Line Canal of the recently completed Haveli Project.

The formula can also be used for the control of silt in an old canal system. Considerable trouble is being experienced on the Upper Bari Doab Canal, Punjab, due to the coarse silt entering the head. Silt excluders have now been designed and are to be constructed. In this case the de-silted water will tend to pick up silt already present on the bed of the channel with the result that unless measures are taken to prevent it the silt trouble will be transferred to the lower portions of the system. The canal can be divided into sections and, knowing the grade of silt on the bed and the discharge passing through these sections, the slope required to prevent the movement of silt can be calculated. By the construction of falls, the slope can be reduced below that necessary for silt movement and, hence, the canal can be stabilized with reference to the bed silt now present. It is intended to stabilize the Upper Bari Doab Canal by this method.

In order to design silt excluders and extractors it is necessary to know the distribution of silt in the depth of water to be treated. This having been determined, models are constructed to simulate the conditions at the excluding or extracting site. The models are studied with the object of fixing the depth to which extraction can take place, the discharge to be run to secure maximum efficiency, and the pressure conditions in the extractor which govern design. An account of the model experiments in connection with the design and operation of the silt excluder on the Upper Bari Doab Canal has already been published [McKenzie Taylor, 1937].

III. Rise of the water-table and waterlogging

The introduction of irrigation is almost invariably followed by a rise of the water-table which may under certain conditions lead to waterlogging. To the rise in the water-table has also been attributed in the past the deterioration of land due to the accumulation of sodium salts in the surface layers of the soil.

In the Punjab attention was first drawn to the subject of waterlogging by the conditions on the Western Jumna Canal. Malaria became a serious menace in the cantonments situated in the irrigated areas of this canal about the year 1857. The Government of India ordered the realignment of the canal and the construction of a drainage system in order to ameliorate the conditions.

In 1870 the rise of the water-table led to waterlogging in certain areas irrigated by the Sirhind Canal. Notes made by the Executive Engineers of this time show that they attributed this rise in the water-table to rainfall, but a systematic investigation of the cause of the rise was not possible owing to the absence of data. Observations of the water-levels in wells was started in 1870 in the Sirhind Canal area, and it has been the practice since that date, for each new canal constructed, to lay out a series of lines of wells in order to obtain a record of the variations in the water-table levels. These observations of the water-levels in the wells are made twice a year, in June and in October. In June, following a long dry period, the water-table is at its greatest depth from the surface. The variations in the June-to-June readings of the water-level give a measure of the permanent additions to the water-table. The readings of the well levels in October are made when the water-table is at its minimum depth from the surface following the monsoon period. Additions to the water-table made by the monsoon are obtained by comparing the June and October records of the well levels. A large number of rain-gauge stations have been established in the areas commanded by the canals, discharge measurements at control points in canal systems are available and river gauges are recorded daily. With the data now available from these records it has been possible to examine the rise of the water-table with reference to the factors which may be operating.

Before discussing the investigations which have been undertaken, it is necessary to draw attention to the geodetic survey which was made by Wilsdon and Bose which has been previously mentioned. The geodetic survey showed the presence of an underground rock ridge running across the Punjab at right angles to the direction of the flow of the rivers. This underground ridge divides the Punjab into two parts in which the water-table is behaving differently. Upstream of the rock ridge the water-table has approached the soil surface and in certain portions of the area waterlogging occurs. Downstream of the rock ridge the water-table is at a considerable distance from the soil surface and its rate of rise is constant at one foot per year over a considerable area. The first investigations that were undertaken on the rise in the water-table were made in the area upstream of the rock ridge ; recently they have been extended to the area downstream of the rock ridge.

The first systematic study of the available data was made by Wilsdon and Sarathy [1927-28] for the area of the Rechna and Chaj Doabs upstream of the rock ridge. They weighted the data of the rain-gauge stations and observation wells so that the records might be truly representative of the whole area. They combined the weighted rainfall with the recorded irrigation in such a way that the total water applied (*W*) was represented as six independent variables of a fitted ploynomial of the fifth order. In order to eliminate secular changes from the weighted records of well fluctuations the best exponential curve was fitted. The change in average well levels, corrected for slow change, was correlated with the constants of the polynomial fitted to the (*W*) distribution. Regression curves were thus obtained which indicated a considerable variation throughout the year in the proportion of water which reaches the water-table from each application. An example of the regression curves obtained is given in Fig. 1. The conclusion reached was that both the rainfall and irrigation contributed to the rise in water-table, but that the major cause of the rise was the monsoon rainfall. As a result of their work they recommended canal closures in order to reduce the seepage component of the irrigation load. This measure was tried, but it resulted in dislocation of the agricultural system, and has now been abandoned as an anti-waterlogging measure.

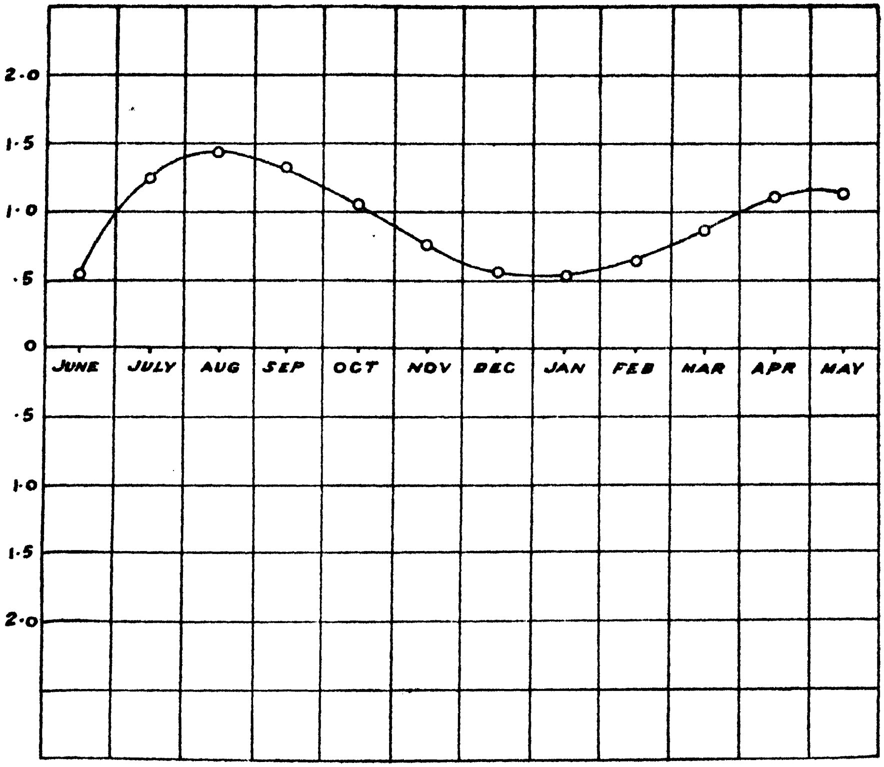

FIG. 1. Monthly regression curve of rainfall for the Upper Chenab Canal (1907-08 to 1930-31)

The well observations, rainfall and canal discharge data for the Upper Chenab Canal area were examined by McKenzie Taylor, Malhotra and Mehta [1933]. This area was also situated upstream of the underground rock ridge. The conclusions they reached confirmed those of Wilsdon and Sarathy regarding the importance of the monsoon rainfall as a factor in the rise of the water-table. The relation between the rise of the water-table and the monsoon rainfall in the Upper Chenab Canal area is shown in Fig. 2 and is expressed by the equation.

$$\delta d = 1{\cdot}54\,R - 3{\cdot}77$$

where δd is the rise in the water-table, and R is the rainfall in inches. They discussed the importance of this equation with reference to drainage and the stabilization of the water-table.

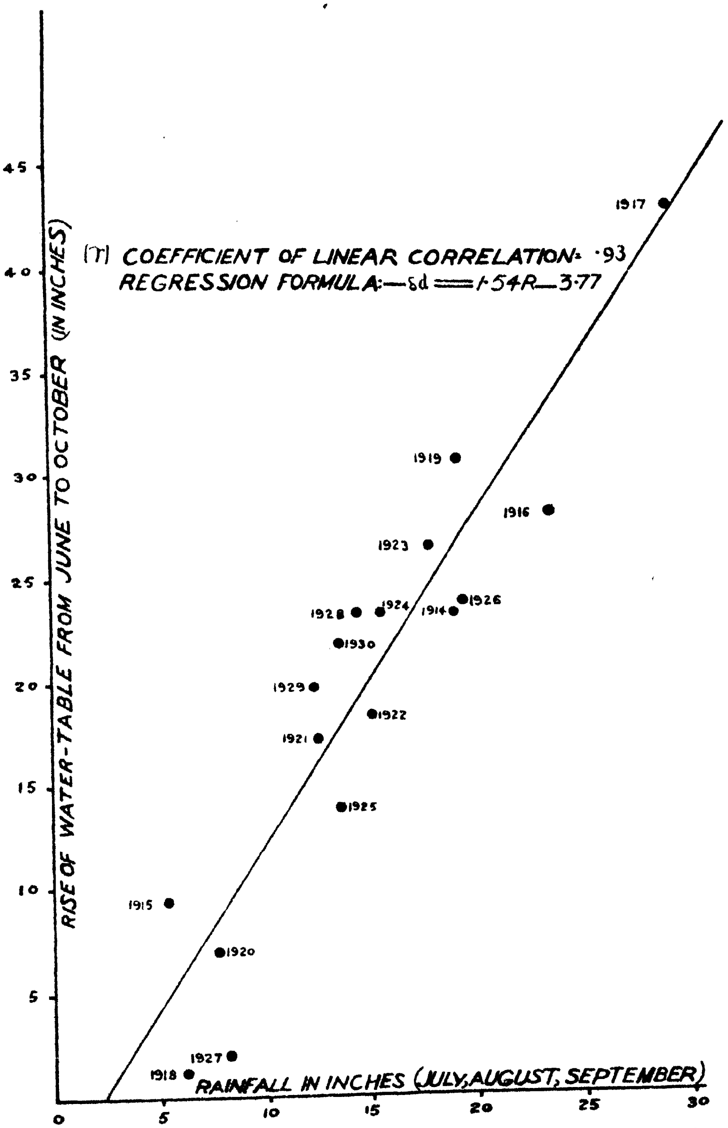

FIG. 2. Rainfall (July-Sept.), rise of the water-table (June-Oct.) 1914-30, Upper Chenab Canal area

As a result of the study of the Upper Chenab Canal area it was suggested that a drainage system to deal with the storm water of the monsoon period should be constructed. A comprehensive drainage system has been under development for the past five years and it seems probable from the results already achieved that the water-table in this area may be stabilized.

An investigation of the rise of the water-table in the Rechna Doab downstream of the underground rock ridge has recently been carried out by Malhotra [1938]. The methods he used were similar to those of the previous workers and he concluded that either the same factors were operating upstream and downstream of the rock ridge or that the water-table upstream of the rock ridge was directly influencing that downstream.

It has been suggested that the presence of the underground ridge has resulted in the heading up of the sub-soil stream and that the rise of the water-table downstream of the ridge is now taking place due to the underground water flowing over the crest. Some support is lent to this theory by the comparison of the conditions in the Punjab with those of the United Provinces. The geodetic survey has shown that the underground ridge is continuous through the Punjab and the United Provinces. In the Punjab, the underground ridge crosses the direction of the flow of the river systems and waterlogging occurs upstream of the ridge. In the United Provinces the underground ridge runs parallel to the direction of the flow of the river systems and, although irrigation has been developed considerably, no waterlogging is reported from the United Provinces.

The irrigation load may be divided into two parts with reference to additions to the water-table . A certain amount of water is lost by seepage from canals and added to the water-table. Of the water used for the irrigation of crops a certain amount passes to the sub-soil and may raise the water-table. Since seepage and irrigation are almost constant from year to year, it is impossible to analyse their effects by statistical methods.

During recent years considerable attention has been devoted to seepage losses and a number of methods have been used for their determination. Malhotra [1936] investigated the losses for the Jhang Branch, Lower Chenab Canal, and for a reach of the Kasur Branch of the Upper Bari Doab Canal. In these cases discharges were taken at the head and tail of the reaches under investigation by means of carefully calibrated current meters. In order to eliminate instrumental, experimental and personal errors the observers and instruments were so changed between the head and the tail of the reaches that the errors could be determined by statistical methods. In the case of the Jhang Branch, Malhotra found the losses to be 13 cusecs per million square feet of wetted perimeter and for the Kasur Branch 7·5 cusecs per million square feet of wetted perimeter.

Vaidhianathan [1938] used a physical method for determining the seepage on a cross-section of the Lower Bari Doab Canal. He sank a series of pipes into the water-table on a line at right angles to the canal. The resting levels of the waters in these pipes were taken after a long canal closure. On reopening the canal he observed the rises in water-levels in these pipes until a steady gradient from the canal had been established. Knowing the moisture content and the transmission constant of the sand above the water-table he calculated the seepage flow and found it to be, in this case, five cusecs per million square feet of wetted perimeter.

Crump installed three sharp-crested weirs of the Rehbock type on the Kasur Branch of the Upper Bari Doab Canal in the same reach as that investigated by Malhotra. These sharp-crested weirs are very sensitive to aeration and great care is necessary to ensure that they are identical. Having taken the necessary precautions, Crump has shown that Malhotra's figure of 7·5 cusecs per million square feet of wetted perimeter is probably correct.

A further investigation of seepage has been undertaken by Blench [1939] who has considered the discharge records of the canal for a period of 20 years. Difficulties in dealing with these records have arisen owing to the methods of measurements varying from site to site. If the methods of measurements of discharge are not similar, then errors are introduced and the results are not comparable. Blench has attempted to correct the discharge records by re-calibrating the flumes according to one method. His results show that on the average seepage losses from the Punjab canals may be taken to be eight cusecs per million square feet of wetted perimeter with an observed maximum of 25 cusecs per million square feet of wetted perimeter, depending upon the type of soil forming the bed of the canal.

Assuming that the average figure of eight cusecs per million square feet of wetted perimeter is correct, it will be seen that canals may make considerable additions to the water-table by means of their seepage losses. Attempts have been made to evaluate the additions to the water-table by considering the June-to-June figures. The results obtained in the Lower Chenab Canal agree closely with the calculated losses from the main line and branches of the Lower Chenab Canal itself. The conclusion has been drawn that, if seepage could be prevented, the water-table would be stabilized. Superficially this may seem a reasonable conclusion. A detailed examination of the rise, however, shows that it is so uniform in magnitude over the whole area of the doab that it seems unlikely that the additions to the water-table on a series of isolated lines can be an important factor in the general rise. Figs. 3 and 4 show the uniformity of the rise at five-year intervals on a cross-section and

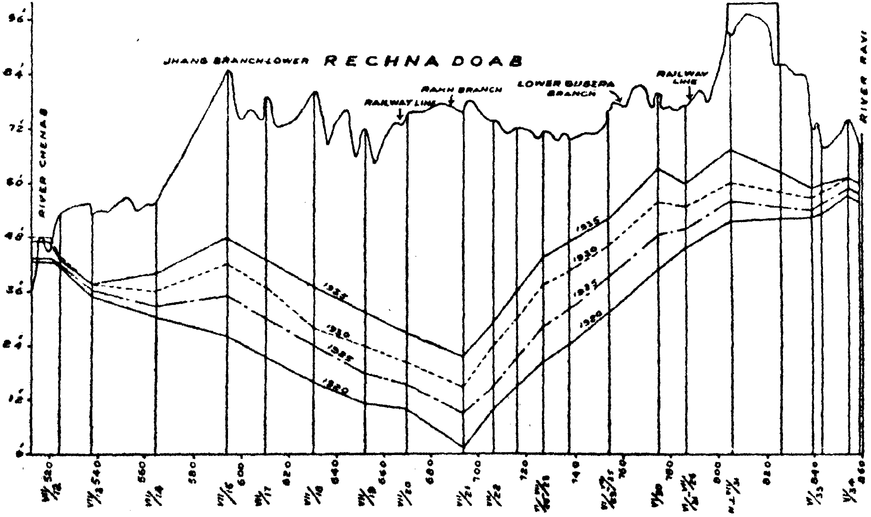

FIG. 3. A section of provincial well line No. XII

Scale {Horizontal 1 in. = 16 miles
Vertical 1 in. = 40 ft.

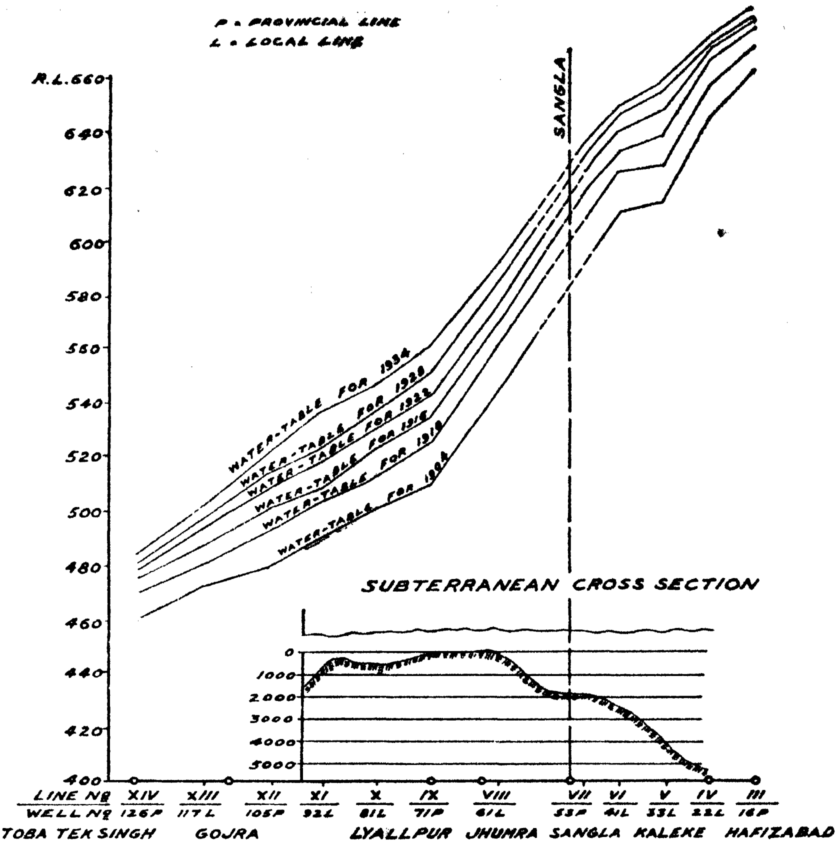

FIG. 4. Longitudinal section showing sub-soil water levels at various periods in the Rechna Doab

(Scale 1 in. = 32 miles)

a longitudinal section of the doab. These sections are typical of the whole area. Lining of canals is probably to be undertaken, but it is doubtful whether it will prove an effective anti-waterlogging measure.

Mehta [1938] has recently carried out experiments to determine the additions made to the water-table by the irrigation of cotton and rice. Pipes were inserted in plots under these crops and in the surrounding areas. Water-table levels were recorded before irrigation commenced and after each irrigation during the growing period of the crops. The results which he has obtained so far show that with the normal irrigation of cotton the water-table under an irrigated area rises 9 in. during the growing period of the crop. In the case of rice the rise of the water-table was almost 4 ft. He calculates that 11·3 per cent of the total water used for rice and 3·5 per cent of the water used for cotton are added to the water-table. As irrigation is evenly distributed over the culturable commanded area of a canal it appears that the irrigation water added to the water-table is an important factor of a uniform nature. Further work on this subject is in progress so that data may be available for reaching reliable conclusions.

The importance of determining the part played by the various factors in the rise of the water-table lies in the decisions that must be taken to prevent waterlogging. In the year 1926 the position was regarded as so serious that a Waterlogging Enquiry Committee was established. As a result of the investigations of this committee Lindley [1928] forecast areas which would become waterlogged within a period of 10 years if the same rate of rise continued. In 1937 an investigation was undertaken to determine how far Lindley's forecast had been fulfilled. It was found that the areas that could be classified as waterlogged were considerably less than had been forecast. An examination of the well records was made, and it was found that as the water-table approached the surface the rate of rise declined and finally the rise ceased. An examination of the soil crust in the areas surrounding these wells has shown that the water-table does not enter the soil crust and that the rise ceased when the water-table touched the lower side of the crust. This conclusion is probably peculiar to the Punjab since the soils are alkaline and frequently the soil crust becomes impermeable. If the bottom of the soil crust becomes impermeable, then the rise of the water-table may not be so serious as was once thought from the waterlogging point of view. From the examination of a large number of wells it has been shown that if the soil crust is 10 ft. or more in thickness then the normal indications of waterlogging are not apparent at the soil surface. At the present stage of the investigation it is possible to say that areas in which the soil crust has a minimum thickness of 10 ft. are in no danger of waterlogging. It is now proposed to carry out a soil survey to enable a forecast to be prepared of danger areas on this basis.

IV. DETERIORATION OF LAND DUE TO THE ACCUMULATION OF SODIUM SALTS

It is generally recognized that the introduction of irrigation in a semi-arid region is followed by the accumulation of salts in the surface layers of the soil. It is unfortunate that until recently soil surveys were not made as a preliminary to project preparation, so that soil conditions in the pre-irrigation period can only be surmised.

The formation of salt soils under irrigation has been attributed, in some cases, to the salts present in the irrigation water. Analyses of the canal waters show that this cause is not effective in the Punjab. Until recently the explanation of the deterioration of land, which found most general acceptance was that the salts were derived from the water-table as a result of its rise and the evaporation of water at the soil surface. It is probable that this view was accepted because the investigations had been confined to areas with a high water-table. Doubts have now been thrown on this explanation as the result of the extension of the investigations to areas in which the water-table is at a considerable distance below the soil surface and contact between the water-table and the soil surface is precluded.

The salt responsible for the deterioration of the Punjab soils is sodium sulphate. Sodium chloride and sodium carbonate may be present, but usually in small quantities. An examination of the soil profiles of unirrigated areas has shown that sodium sulphate is distributed throughout the soil crust, It appears, therefore, that it must have been deposited along with the alluvium now forming the soil. The origin of the salt present in the Sambhar lake, Rajputana, which is situated to the south-east of the Punjab has been investigated by Holland and Christie [1909-23]. They attribute the replenishment of the salt in the lake to the salt-laden wind blowing from the Rann of Cutch and the deposition of the salt in the Sambhar lake region. This explanation may be valid for the Sambhar lake, but cannot apply to the Punjab where the salt present is sodium sulphate. A possible explanation of the presence of sodium sulphate in the alluvium of the Punjab is indicated by the fact that sodium sulphate is deposited from a solution of mixed salts at a temperature of —3°C. Glacial conditions are known to have occurred in the Punjab, and it appears probable that the sodium sulphate was deposited along with the alluvium during a glacial period. Support is lent to this suggestion by a consideration of the extension of the alluvium into Sind where the main salts present are sodium chloride and calcium chloride and sodium sulphate has become of minor importance.

For the past 12 years revenue officials have been making annual surveys of selected areas to determine the rate at which land is going out of cultivation. The data show that the recorded rate is of the order of 25,000 acres per annum. This figure may be regarded as a minimum, since land is known to be going out of cultivation in areas not under survey and the accuracy of the revenue records is open to question. A recent check of a revenue survey by means of photographs taken from the air indicates that the rate of soil deterioration is much higher than 25,000 acres per annum.

In order to investigate the theory that the rise of the water-table was the primary cause of the formation of salt efflorescence and to obtain data as to the depth at which the water-table might become active in this connection, a series of villages with the water-table at varying depths below the surface, as indicated by the water-depth maps, was selected for observation. The depth of the water-table in these villages varied from 9 to 40 ft. No deterioration of land due to salt had been recorded in the selected villages. On inspection it was found that in each village deterioration was in progress, the probable rate of deterioration being 5 per cent of the cultivated area per annum.

A detailed examination was made of the soil conditions in these areas. Pit were dug to the water-table and the soil profiles of both good and deteriorated lands examined. The soil crust was generally 10 ft. in thickness and rested upon a grey sand in which the water-table was situated. The sand below the soil crust had a moisture content of between 4 and 5 per cent down to the water-table. On analysis it was found that in the good land a zone of accumulation of salt was present in the soil crust some distance below the surface. In the deteriorated lands the zone of accumulation of salt was situated within 2 ft. of the soil surface. In no case was salt found in the sand layer. From these observations it was concluded that the salt causing the deterioration was not derived from the water-table and that the rise of water-table was not an essential factor in the formation of a salt efflorescence at the soil surface. Had the salt been derived from the water-table, the zone of accumulation would have appeared only at the surface as in this formation evaporation would produce its maximum effect.

The investigation was now extended to unirrigated areas to determine the natural distribution of salts in the soil crust and the changes which occur in this distribution as the result of the introduction of irrigation. Plots of land which had not received irrigation water were selected, and their soil profiles were examined for salt distribution. Cropping systems were introduced on these plots which represented normal agricultural practice in the Punjab, and the distribution of salt in the profiles was determined after each harvest. An account of this investigation has already been given [McKenzie Taylor, 1938] so that only a brief summary of the results need be presented now.

Figs. 5 and 6 illustrate the effects on salt distribution in the profile resulting from the introduction of irrigation and the growth of cotton and rice. In the case of cotton it will be seen that irrigation has caused a re-distribution of salts originally present in the soil crust. A zone of salt accumulation has been formed similar to that which had been shown to be present in the normal irrigated areas. In the case of rice no zone of accumulation has been formed, but the salt appears to have been washed completely from the soil crust into the underlying sand layer. These observations have important applications to both the prevention of land deterioration and its reclamation.

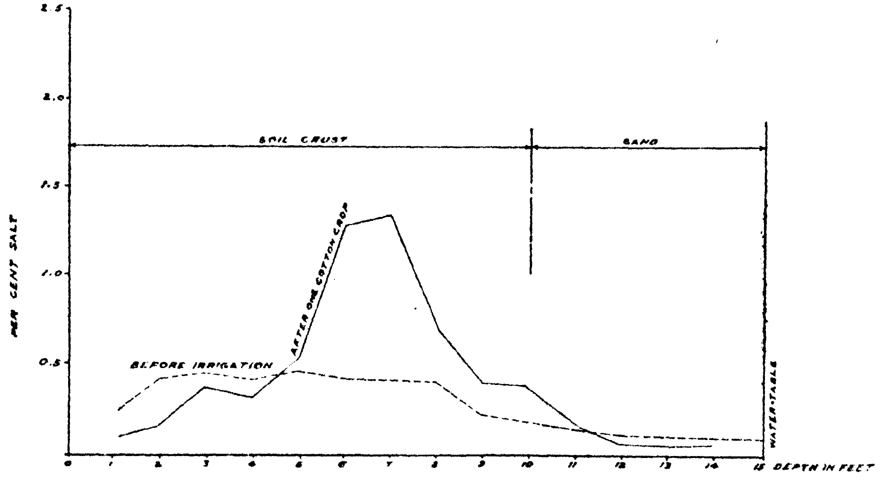

FIG. 5. Distribution of salts before and after a cotton crop at Jaranwala

Having established that a zone of salt accumulation was formed under cotton irrigation, the subsequent history of this zone with different crops was studied. It has been established that if the irrigation water supplied is sufficient to moisten the soil to the depth of the zone of salt accumulation but it is insufficient to balance that lost by transpiration and evaporation, then the tendency is for the zone of salt accumulation to move towards the surface. If the amount of irrigation water is sufficient to counterbalance the losses due to transpiration and evaporation, then the zone of accumulation of salt remains stationary or moves in a downward direction. It seems therefore that in the Punjab it is necessary to study not only the water requirements of the crops but also the water requirements of the soil with respect to the possibility of deterioration.

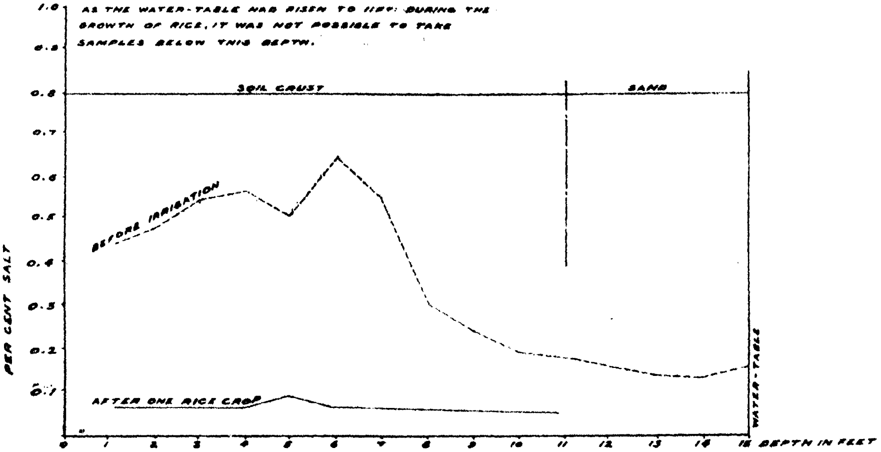

FIG. 6. Distribution of salts before and after a rice crop at Jaranwala

As has been indicated, the water requirements of the soil are of considerable importance. The recognition of this fact led to an examination of the intensity of irrigation in the Lower Chenab Canal area, a portion of the province in which deterioration is taking place at a rapid rate. The intensity of irrigation is the percentage of the culturable commanded area that is irrigated. A diagram illustrating the increase in the intensity of irrigation on the Rakh Branch of the Lower Chenab Canal is given in Fig. 7. From this figure it will be seen that during the last 29 years the intensity of irrigation has continually increased so that the available water is now spread over a much greater area than formerly. Since the general tendency in the area irrigated by the Lower Chenab Canal is for the salts to move towards the surface, it must be concluded that with the present intensity of irrigation the amount of water supplied per unit of area irrigated is insufficient to counterbalance the losses from the soil due to transpiration and evaporation. The increase in the intensity of irrigation is probably due to the increase in population which has been taking place during the last 20 or 30 years, since it is necessary to provide both food and clothing for a greater number of people. The problem has therefore both social and engineering aspects.

From the investigations so far described the essentials of land deterioration in the Punjab appear to be :

1. the presence of salt in the soil crust,
2. the formation of a zone of accumulation of salts in the soil crust with the introduction of irrigation,
3. the intensity of irrigation which determines the position of the zone of accumulation of salts at any time within the soil crust.

The results obtained from the irrigation of rice and illustrated in Fig. 6 are of considerable importance in connection with both the prevention of land deterioration and the reclamation of deteriorated land. If on the introduction of irrigation rice is the first crop grown, it will be seen that the whole of the salt present in the soil crust can be removed to the underlying sand layer. The results of reclamation experiments to be mentioned later and also investigations in the laboratory have shown that once the salt has been removed from the soil crust to the underlying sand, there is little danger of its return to the soil surface. Deterioration of land containing salts can, therefore, be prevented by the growth of a rice crop in the initial stages of irrigation. At the beginning of a project, when irrigation water is available in large quantities owing to the undeveloped nature of the area, such a practice is possible. With a developed area engineering difficulties, connected with increased channel supplies in the summer while maintaining normal supplies in the winter, are introduced. The solution of the problem of variable supplies, as has been indicated earlier in this paper, is the introduction of modular outlets.

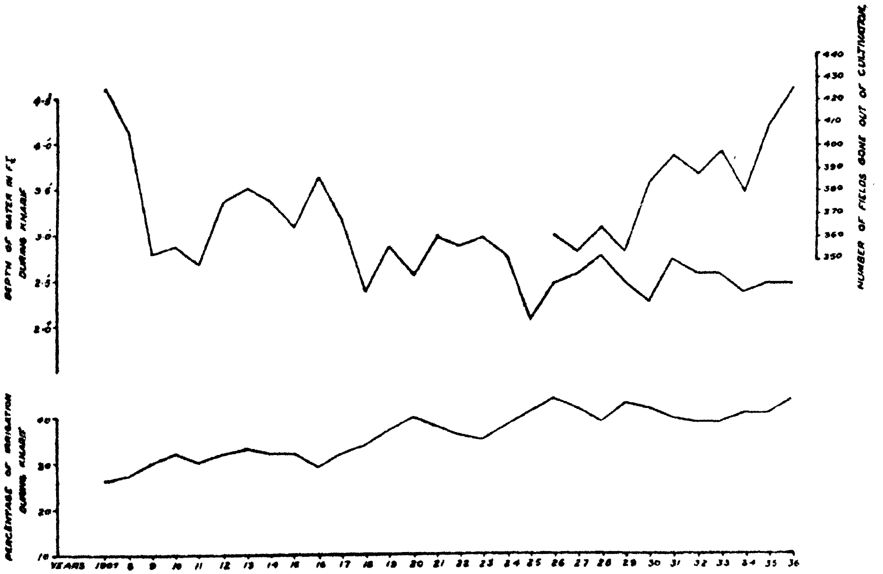

FIG. 7. Curves showing the intensity of irrigation during *kharif*, the delta used during *kharif* and the number of fields gone out of cultivation (Rakh branch, Lyallpur division)

Experiments on reclamation have been in progress for the last nine years. It has been shown that if reclamation is attempted immediately deterioration commences, it can be successfully completed in one year. The longer the reclamation is postponed after deterioration has taken place, the greater is the difficulty experienced owing to the development of increasing alkalinity in the soil. The basis of reclamation, as now practised in the Punjab, is the growth of rice. Before the rice is transplanted the area is leached until the salt content is considerably reduced. The heavy irrigations given during the growth of the rice crop completely eliminate the salt from the soil crust. The alkalinity which develops on the removal of salt appears to be removed by the action of the roots of the rice plant. The carbon dioxide formed by the roots appears to convert the sodium of the sodium clay into sodium bicarbonate, as indicated by an analysis of the drainage waters. With the removal of alkalinity the soil becomes permeable. It has been shown that, since rice is grown under anaerobic soil conditions, the available nitrogen present in the soil following the rice crop is small in quantity. In order to re-establish the nitrogen balance in the soil a leguminous crop, such as berseem or *senji* (*Melilotus parviflora*), follows rice. A normal rotation of crops is then introduced. The experiments so far carried out have shown that when land has once been reclaimed no deterioration takes place, as indicated by both soil analyses and crop yields, within a period of eight years under the Punjab soil conditions.

During the course of the investigations further interesting observations were made regarding the behaviour of soils in the Punjab containing sodium sulphate. It is characteristic of the Punjab that the salt efflorescence appears in the winter months and disappears in the summer. Sodium sulphate can be present in either the anhydrous or a number of hydrated forms and can go into solution in its own water of crystallization when present in the form of the deca-hydrate. Further, it has been shown by Puri [1937] that soils containing sodium sulphate can abosrb, under certain conditions of humidity and temperature, considerable quantities of moisture from the atmosphere. As a result of this abosrption during a period of high humidity and low temperature, when conditions are again suitable for evaporation to occur a moisture gradient is established in the soil, and there is a tendency for the movement of salt towards the surface. These observations account satisfactorily for the appearance of salts in the winter when humidity and temperature conditions at night are suitable for moisture absorption and in the day-time for evaporation. In the summer period either humidity or temperature or both are unsuitable for moisture absorption by sodium sulphate.

The absorption of moisture by the soils containing sodium sulphate affords an explanation of the zemindar's observations that the best yields of crops are obtained immediately before land goes out of cultivation due to the accumulation of salt. Water is always the main factor limiting crop production in the *rabi* season in the Punjab. If a soil contains sodium sulphate, in an amount insufficient to be directly toxic, water can be abosrbed by the soil up to about 15 per cent by weight. Under these conditions, the crop is unlikely to suffer from water shortage at periods of high atmospheric humidity, and hence the yield of the crop is unlikely to be limited by the water supply factor. Excellent crops of wheat have been observed growing on land during the *rabi* season and the land has gone out of cultivation within a year due to salt efflorescence.

V. TUBE-WELLS

With the completion of the Kalabagh weir which is now under construction on the Indus for the irrigation of the Thal area, the whole of the available supplies of water in the Punjab rivers will be used for irrigation. Considerable areas remain in which famines occur and for which water is not available. Two courses for the further development of irrigation are open to Government, and both are now under investigation. The first course that may be adopted is the storage of water by means of high dams in the catchment areas. This course is open to objection as in order to fill the reservoir all flood water independent of its silt content will have to be stored. The life of the reservoir under these conditions may not be long. The second course that is open to Government is to install tube-wells driven by electricity. In certain areas this seems to be the more promising line of action to take.

Tube-wells have already been developed to a considerable extent in the United Provinces. At the time of their construction little information was available as to the factors determining design, and the effect of pumping on the stability of the water-table was not considered. An investigation was carried out on the latter subject during the construction period [McKenzie Taylor, 1935]. From a consideration of the monsoon rainfall, the variations in sub-soil water levels as indicated by wells, and the amount of water to be withdrawn from the sub-soil by pumping, it was possible in this case to state, as a result of a statistical examination, that over a period of a climatic cycle the pumping of the water from the tube-wells would be unlikely to affect the stability of the water-table, since the variation in the monsoon rainfall were much greater than the proposed withdrawals, and hence depletion of the water-table in years of low rainfall would be made up in years of high rainfall. The working of the tube-wells in the United Provinces has so far confirmed this prediction.

The rainfall in the eastern portion of the Punjab, for which a tube-well project is being considered, is similar in amount and distribution to that of the United Provinces. An examination of the rainfall and water-table records with reference to the proposed withdrawals is now being carried out. The indications are that in the sub-montane tract of the area there is little danger of the depletion of the water-table.

In the Punjab a factor which militates against the use of the sub-soil water for irrigation is its high salt content. The water is situated in a series of sands which are separated from each other by bands of clay. A considerable number of trial borings have been made and a sample of water from each of the water-bearing sands down to a depth of about 300 ft. has been obtained for analysis. The analysis made to determine the suitability of water for irrigation is based on an investigation which was carried out to determine the concentration of salts in solution which would cause soil deterioration and the ratio of the calcium to sodium content of the water which would prevent base exchange between the soil and the water taking place. As a result of this investigation a formula for the salt-index, by which the suitability of the water for irrigation could be judged, was devised by Puri [1937]. The formula is as follows :—

$$\text{Salt-index} = \text{Total Na} - 24{\cdot}5 - [(\text{Total Ca} - \text{Ca as CaCO}_3) \times 4{\cdot}85]$$

All quantities in the above formula refer to parts per 100,000. The salt-index is negative for all good waters and positive for those unsuitable for irrigation. Generally it may be said that waters with a total salt content of under 60 parts per 100,000 are suitable for irrigation, those with a salt content between

60 and 120 parts per 100,000 are suitable if the salt-index is negative, and waters with a salt content above 120 parts per 100,000 are unsuitable for irrigation even though the salt index is negative.

A considerable amount of model work has recently been done to determine the relation between the drawdown and the discharge, the diameter of the strainer and the discharge, and the effect of shrouding on the yield. In order to carry out this work a method for determining the transmission constant of water in sands had to be devised. An account of the method and apparatus used has already been published [Singh, Luthra and Vaidhianathan, 1937].

Fig. 8 illustrates the apparatus used for studying tube-well design. In order to investigate the relation between the discharge and the drawdown, the dimensions of the strainer, the packing of the sub-soil and the depth of water in the well were kept constant. The drawdown was then varied and the discharge for each drawdown was obtained by pumping from the model of the well. In the second portion of the experiment the same data were observed for varying diameters of the strainer and the depth of water in the well. For each case in which the latter two quantities had fixed values, the discharge was plotted as ordinate and the drawdown as abscissa and the plotted points joined by a smooth curve. The curves, showed a more than proportionate increase in discharge for increases in drawdown. It was found that if the first observed point (for the lowest drawdown) was joined to the origin (which automatically lay on the curve as the discharge for a zero drawdown is zero) and the line joining them produced, the other points on the curve were seen to lie above this line. An analysis of the curves by fitting suitable formulæ by statistical methods was carried out. It was shown that the usually accepted linear relationship between Q, the discharge and H, the drawdown $Q=C.H$ was incorrect and the quadratic of the formula $Q=C_1.H+C_2.H^2$ fitted the results within an accuracy of 3 per cent. It was also shown that the coefficient of H increases with the depth of water in the well and with the diameter of the strainer, but doubling the diameter of the strainer only increased the discharge by 12–20 per cent.

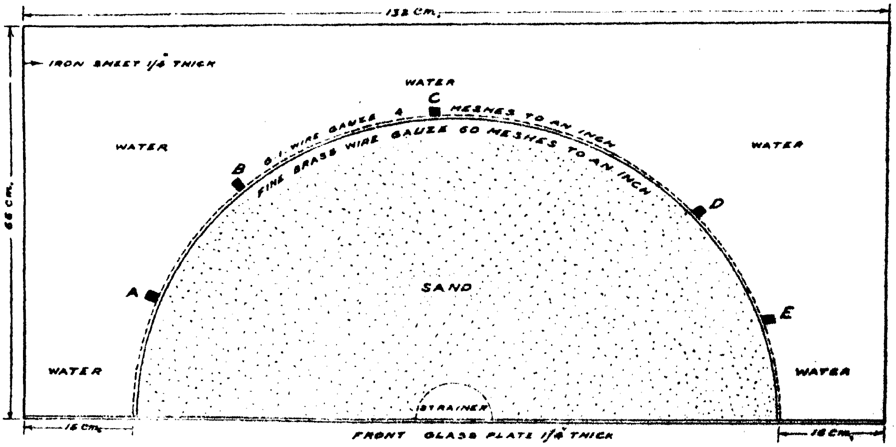

Fig. 8. Tube-well tank.

The conclusions drawn from the model experiments may be stated as follows :—

1. Under field conditions the yield of a tube-well is proportional to the drawdown. If the strainer length is short and the drawdown large, this relation does not hold.

2. The increase in the yield of a tube-well is not proportional to the surface area of the strainer as has generally been accepted. The yield increases very slowely with the increase of diameter.

3. Shrouding may be employed as an alternative to increasing the diameter of the strainer. There is, however, a critical grade of shrouding material for each mean diameter of the water-bearing sands. Increasing the diameter of the shrouding material beyond this point does not increase the discharge of the well, since the main resistance to the flow into the well is from the water-bearing sand.

4. Equal lengths of strainer are more effective if they are situated in deep and continuous permeable strata than if they are in short lengths situated in sands which are bounded by impermeable layers.

The results of these experiments have been applied in the field to the selection of the water-bearing sands from which water should be withdrawn and for determining the size of the strainer to be used. For each bore that has been made samples of the water-bearing sands have been examined for their transmission constants. If the transmission constant, as determined by the apparatus to which reference has been made, is below 0·0001 ft./secs., then the sand is unsuitable as a water-bearing medium for tube-well purposes.

An important point concerning the life of a tube-well has also been under investigation. In the Punjab it has been found that strainers of tube-wells tend to become clogged as a result of the deposition of calcium carbonate on the strainer surface. A series of tube-wells, the history of the discharge of which was known, was examined. The calcium bicarbonate content of the waters derived from these wells was determined. As a result it was shown that if the calcium bicarbonate content exceeded 20 parts per 100,000, then the deposition of calcium carbonate on the strainer was likely to be rapid and the life of the tube-well short. In addition to determining the salt-index of the water obtained from each of the trial bores, the calcium bicarbonate content of the water was also estimated and the suitability of the sand as a site for a tube-well strainer with reference to its length of life was stated in the report.

An examination of a number of tube-wells of varying discharges was made with reference to the handling of the water by the zemindar. The tube-wells ranged in discharges from 1·0 cusec to 5 cusecs. It was found that the zemindar could not handle a five-cusec discharge economically and that such a discharge led to a considerable waste of water. The investigation showed that a tube-well with a discharge of 1·5 cusecs was the most suitable for the irrigation of small holdings such as occur in India.

VI. DISTRIBUTION OF IRRIGATION WATER AND THE METHOD OF ASSESSMENT

It has already been stated that a typical canal system consists of a head works, main line, branches, distributaries and minors. In the distributaries and minors, outlets are fixed which discharge into the zemindar's watercourses and from which the fields are irrigated. In the upper portions of the doabs * the canals are of two types—perennial and non-perennial. Perennial channels run throughout the year, while non-perennial channels are opened on 15 April and are closed on 15 October; in other words, the non-perennial channels irrigate only in summer when the water supply in the rivers is high. The non-perennial channels are, as a rule, situated in the head reach of the canal above the point on the main line where the distribution of the perennial supplies begins. The existence of a number of non-perennial channels in the head reach of the canal is made possible because extra supplies can be run in the main line during summer without affecting the perennial channels lower down. These non-perennial channels in the head reaches of the doabs can be called rice canals, for rice is the most important crop grown in the areas commanded by them.

Instances of non-perennial canals do occur in the lower reaches of the doab. In such cases, although rice still forms a major portion of the cultivation, other crops such as cotton are grown but the area cultivated and the yield obtained is uncertain . On the non-perrennial canals the area irrigated varies between 25 and 40 per cent of the culturable commanded area. The duty of water on these canals is lower than on the perennial channels.

The perennial channels are usually designed to irrigate 75 per cent of the culturable commanded area with a *kharif* to *rabi* ratio of 1 : 2, i.e. they are designed to provide water for 25 per cent of the area in summer and 50 per cent of the area in winter. Lately, however, the cultivators have exceeded the limit of 75 per cent irrigation, although the water supplies in the canals have remained unchanged. This increase in the irrigated area with the same available water supply and its effects will be dealt with in more detail when discussing land deterioration and reclamation.

For the actual distribution of water amongst the cultivators one must consider the supply at the outlet on the distributary and the watercourse. The outlet, as a general rule, is designed to deliver 1·0 to 2·0 cusecs of water, which supply a zemindar can conveniently handle during the course of irrigation. The total area irrigated by any one outlet is called a *chak* and the zemindar is not permitted to carry water from one *chak* to another even though he may be the owner of both the *chaks*. The area which is to be irrigated is divided into squares. Each square is composed of 25 fields of approximately one acre each.

Water in the watercourse is distributed by means of a system of turns called *warabandi*, which is decided upon by the parties concerned and which is sanctioned by the Divisional Engineer in charge of irrigation. *Warabandi* once fixed cannot be changed unless the parties once more agree to do so and obtain the previous permission of the Divisional Engineer.

The unit for the distribution of water is a square of 25 fields. Turns are fixed for each square and the main watercourse is allowed to be breached for irrigating this area at only one point, the situation of which is shown in the records of the engineer in charge. For the further distribution of water inside the square, the zemindar or zemindars dig their own channels and are free to take water to any of the fields within the time allotted to that square. In the most commonly practised *warabandi*, a square gets a turn of water every ten days. The regulation of the *warabandi* is controlled by a committee of two or three persons of the village and the village priest, who is provided with a clock and gives the time signal for the change of the turn.

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* Tract of land lying between two rivers.

Fig. 10 shows a plan of a typical irrigation system in a Punjab canal colony.

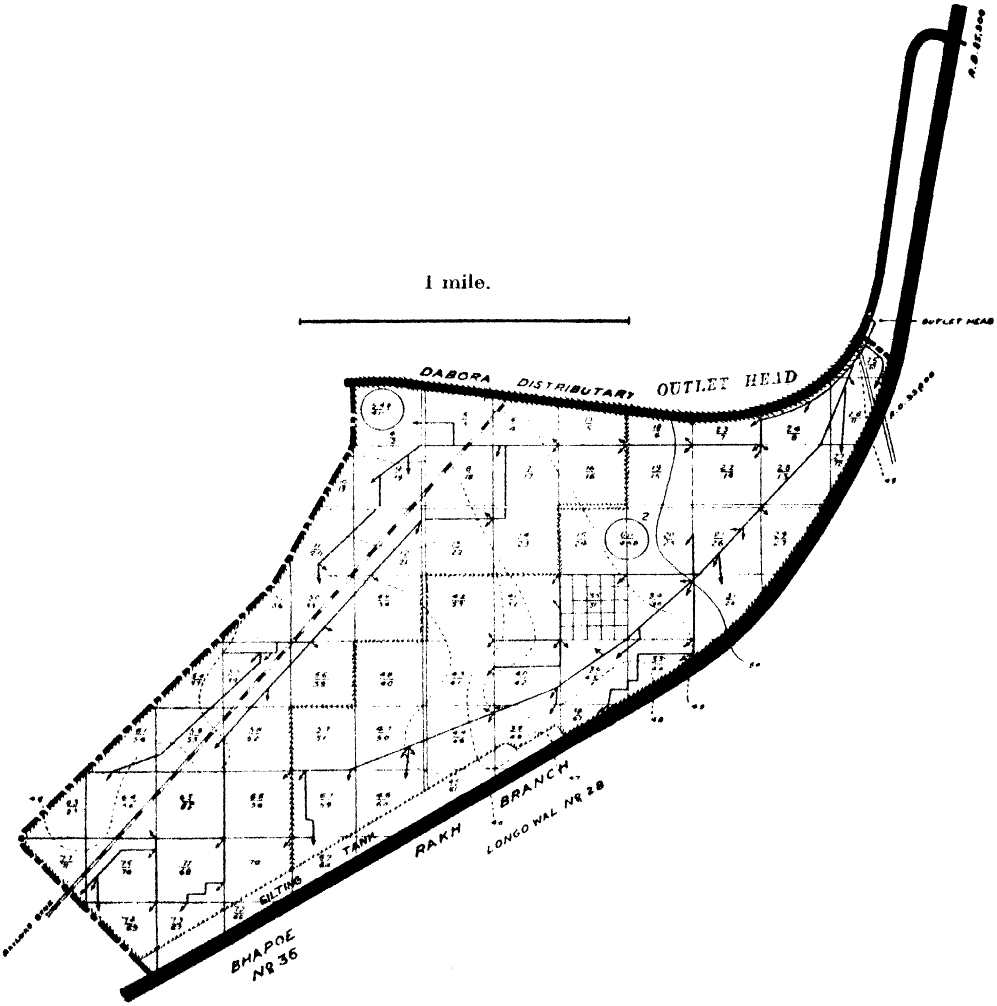

FIG. 9. A portion of the Lower Chenab Canal showing a typical irrigation system.

Scale 1 in. = 7/12 mile.

The system of distribution described above has been evolved as the result of many years of practice and is accepted without question by the zemindars concerned. Difficulties sometimes arise, but these are usually of a temporary nature. For instance remodelling of the distributaries is sometimes necessary on account of silting. This remodelling is frequently accompanied by changes in outlet design which may reduce temporarily the discharges in the watercourses. Since the zemindar knows accurately the area that he can irrigate in a given time, any reduction in this area will be attributed to the remodelling and may be a source of friction between the Irrigation Branch and the zemindar. For some time studies have been in progress with the object of designing an outlet which will give a constant discharge irrespective of the discharge in the parent distributary. At present the Gibb module appears to be the most satisfactory as the fluctuations in discharge into the watercourse do not exceed 5 per cent.

The development of a fixed module is also of considerable importance in connection with land reclamation. In order to reclaim lands additional water supplies must be given. If constant discharge outlets are not fixed, then each outlet will draw a proportion of the increased supply, and as a result the additional water given at the head of a channel will not be available at the reclamation site.

System of water-rate assessment

For the purpose of assessment, the Irrigation Branch appoints revenue officials, called *patwaris*. A *patwari* has a charge of 8 to 10 outlets or irrigation *chaks* and he lives in one of the villages adjoining the *chaks*. He is constantly touring in the area under his charge and maintains a record of all areas irrigated, crops sown, areas matured and areas failed. His work is inspected by the Zilladar and the Deputy Collector and also checked by the Sub-Divisional Officer and the Divisional Engineer.

The charges for irrigation are assessed according to the crops sown, the rates for which have been previously fixed by Government. All fields that have been irrigated are assessed. The rates charged are given in Table I. If the zemindar considers that his crop has failed, he can apply for the remission of the water rate to the Divisional Engineer. A crop is considered as a failure when the yield is less than 25 per cent of that normal for the district. On receiving an application for remission, the Zilladar inspects the standing crop, and if in his opinion the yield is likely to be less than 25 per cent of the normal, the remission is granted.

In order to collect the revenue the *patwari* makes a list of fields irrigated and the crops matured. He prepares an account of the money due from each cultivator and hands a copy of his assessment to the headman of the village with instructions to collect the money and deposit it in the Government treasury. Copies of the accounts prepared by the *patwaris* are forwarded through the Irrigation Department to the Collectors of the various districts, who are ultimately responsible for the Collection of the revenue.

The above method of assessing the revenue is based on the area irrigated and a fixed crop rate. The ideal method for assessment, especially as it would lead to economy in the use of water, would be the volumetric system. In tube-well areas this system has been adopted mainly because it is possible to measure accurately the volume of water under these conditions. Attempts have been made to introduce the volumetric system on the bigger estates, but so far with little success. Two methods of distribution on the volumetric basis are possible : (1) the contract system in which a guaranteed supply has to be delivered, and (2) that based on the cusec-day which means that the actual volume of water delivered must be paid for. The difficulty in the contract system is that the supplies in the river vary and are below general requirements in *rabi*. It is obviously unfair to the other cultivators to guarantee a supply to one man in periods when water is short. The sale of water by the cusec-day has failed largely because methods of measurements are crude, and devices for measurements can easily be tampered with. Before water can be sold volumetrically accurate measuring instruments must be devised, and they must be of such a robust nature that interference with them becomes impossible.

TABLE I

Schedule of water rates in force on the Lower Chenab Canal

Class	Nature of crops	Rate per acre		Per
		Rs.	A.	
I	Sugarcane (except on non-perennial channels)	11	0	Crop
II	Sugarcane on non-perennial channels	9	0	Do.
III	Water-nuts	7	8	Do.
III A	Rice	6	8	Do.
IV	Indigo and other dyes, tobacco, poppy, spices and drugs	6	4	Do.
IV A	Cotton	5	4	Do.
V	Gardens and orchards and vegetables except turnips	5	8	Gardens and orchards per half year and the rest per crop
VI	Barley and oats (except on non-perennial channels)	4	4	Crop
VI A	Wheat (except on non-perennial channels	4	4	Do.
VII	Melons, fibres (other than cotton) and all crops not otherwise specified	4	12	Do.
VII A	Maize	4	0	Do.
VIII	Oilseeds (except *rabi* oilseeds on non-perennial channels)	4	4	Do.
IX	*Rabi* oilseeds, barley and oats on non-perennial channels	2	0	Do.
IX A	Wheat on non-perennial channels .	2	0	Do.
X	*Bajra*, gram, *masur* and pulses . .	3	4	Do.

TABLE I—*contd*

Class	Nature of crops	Rate per acre		Per
		Rs.	A.	
XI	*Jowar, cheena,* grass which has received two or more waterings and all fodder crops including turnips	2	8	Grass per half year, the rest per crop
XI A	Paddock areas as sanctioned by Local Government	3	0	Per half year on the whole area irrespective of whether it be irrigated in part or whole or not at all
XII	(*a*) Watering for ploughing not followed by a crop in the same or succeeding harvest	1	0	Acre
	(*b*) Village and district board plantation—			
	(1) Any number of waterings in *kharif*	1	0	Half year
	(2) One watering in *rabi* . .	1	0	Do.
	(3) Two or more waterings in *rabi*	2	0	Do.
	(*c*) Grass—A single watering in *kharif* or *rabi*	1	0	Do.

NOTE.—Grass given two or more waterings falls under class XI.

Hemp, indigo and *guara* ploughed in as green manure before 15 September are not assessed to water rates.

A further difficulty in connection with the introduction of the volumetric system which has to be faced by the engineer, though not of engineering origin, is the fragmentation of holdings. It is customary on the death of a zemindar for his estate to be divided amongst the relatives. This leads to a man owning a considerable number of small areas of land scattered over a number of *chaks*. Under these conditions it is impossible to supply water on the volumetric basis. The consolidation of holdings is in progress, and must be completed before the volumetric system of assessment can be introduced.

VII. RAINFALL, RUN-OFF AND SOIL EROSION

These three inter-related elements are of considerable importance in a number of matters with which the engineer has to deal. The relation between rainfall and run-off in the hill areas determines the magnitude and frequency of the floods that may be expected in summer and the seepage back to the river in winter upon which the low river supplies depend. In the plains, the design of drains will depend on the same relationship. The introduction of the soil erosion factor into the relationship determines the silt load of the rivers, which, as has been discussed in the section on canals, affects considerably the entry into canals and hence their costs of maintenance. A further important effect of the silt load in the river is that, following the construction of a barrage, silt is deposited upstream due to the reduction in the velocity of the water. The building up of the new regime slope of the river upstream of the barrage may lead to considerable flooding of the surrounding areas. An instance of this is afforded by the river Jhelum since the construction of the barrage at Rasul. The town of Jhelum, situated some 25 miles upstream of the barrage is now subjected to flooding with river gauges considerably lower than in the pre-barrage period. Investigations to determine control measures for run-off and soil erosion are, therefore, of the greatest importance.

Gorrie [1939] has made a wide study of this subject in the Punjab from the point of view of disforestation. It is, however, difficult to obtain field data which provide convincing conclusions in this respect.

In order to obtain some information on the subject a small experimental station was established at Nurpur in the foothills of the Himalayas. Six trays were used in these experiments. Each tray had an area of 3,125 sq. cm., and the volume of water which ran off its surface was measured after each shower and expressed as a percentage of the total amount received during the shower. The soil eroded during the shower was weighed and expressed in terms of the soil that would proportionally be eroded from an acre.

Summary of the data

The quarterly averages for the period July 1937-December 1938 are shown in Table II.

TABLE II

Summary of the results of soil erosion and run-off experiments at Nurpur

(July 1937-December 1938)

Period	Total rain (inches)	Mean percentage run-off					
		Trays		Trays		Trays	
		1	2	3	4	5	6
		Grass		Grass	Scrub	Bare	
		Percentage run-offs					
1937 July—September .	37·89	20·0	21·2	13·2	19·4	38·1	41·5
October—December	9·72	8·5	25·3	3·1	3·9	38·5	40·3
1938 January—March .	10·91	15·8	32·1	7·5	6·6	42·4	51·0
April—June . .	9·01	15·4	13·3	4·1	10·6	49·7	53·1
July—September .	30·31	11·2	12·3	9·1	8·5	60·3	62·0
October—December	0·67	..	..	4·6	1·6	15·5	11·4
Total (18 months) .	98·51	15·1	19·2	9·4	12·2	46·4	49·6

TABLE II—*contd.*

Period	Total rain (inches)	Mean percentage run-off					
		Trays		Trays		Trays	
		1	2	3	4	5	6
		Grass		Grass	Scrub	Bare	
		Material eroded (lb. per acre)					
1937							
July—September	37·89	29·5	36·6	33·1	42·7	169·9	209·4
October—December	9·72	1·5	4·0	0·6	2·4	9·8	12·4
1938							
January—March	10·91	3·4	4·5	1·5	1·2	9·4	12·3
April—June	9·01	3·1	6·0	2·7	3·3	51·9	45·5
July—September	30·31	3·9	5·5	7·2	4·0	220·2	156·1
October—December	0·67	..	Not measured			..	..
Total (18 months)	98·51	41·3	56·6	45·1	53·7	461·2	435·7

The above table shows that :

(1) About half the water received as rainfall by a bare surface runs off and does not soak into the soil.

(2) About one-sixth of the water received by grass-covered land runs off its surface, while for land covered with grass and scrub the proportion is only one-tenth.

(3) Trays with similar cover-grass, or grass and scrub, or no cover behave, within limits, in a similar manner.

(4) The different quarters of the year do not markedly affect the percentages of run-off.

(5) There is a gradual increase (leaving the last quarter out when there is little rain) in the proportionate run-off from the bare trays. In the first six months the run-off was about 40 per cent of the water received, in the next six it was very nearly 50 per cent and in the next quarter it jumped to 60 per cent. The covered trays showed no such changes.

(6) The bare trays lose soil, on an average, at about ten times the rate at which grass and scrub covered trays lose it. The latter two types of cover do not appear to be unlike between themselves.

(7) The greatest loss of soil is in the monsoon months whatever be the type of cover.

(8) It is possible for a bare acre of soil to lose, in 18 months, over 20 tons of surface material, while the covered acre loses barely two tons.

An attempt has been made to use the existing rainfall and discharge data for the upper portion of the river Ravi catchment for an examination of the problem in that area. It was hoped that some evidence would be forthcoming regarding the effects of denudation on the discharges of the river in the winter months and also on the number and intensity of floods in the monsoon. No information was available regarding the extent and progress of denudation as no periodical maps had been made to determine the extent of the area affected.

The enquiry was divided into four parts :

(i) A study of the frequency and intensity of floods above 50,000 cusecs recorded during the last 35 years.

(ii) A study of the average winter discharges for the last 20 years, disregarding freshets.

(iii) Analysis of the rainfall records to discover a possible trend towards an increase or decrease in the average monthly values.

(iv) A study of the inter-relation of floods and rainfall.

TABLE III

Distribution and volume of the floods recorded in each year, along with their dates

Year	Date	Discharge (cusecs)	Year	Date	Discharge (cusecs)
1903	23 July	108,000	1910	29 July	116,000
(4)	10 August	190,000	(5)	1 August	85,000
	7 September	87,000		8 August	75,000
	12 September	83,000		10 September	60,400
				11 September	54,200
1904	6 August	57,000			
(1)			1914	22 July	51,500
			(6)	27 July	75,300
1905	14 July	51,000		28 July	83,520
(3)	12 August	50,000		29 July	51,500
	13 September	85,000		30 July	51,500
				7 September	51,500
1906	14 September	73,000			
(3)	15 September	83,000	1915	1 August	65,250
	16 September	135,000	(1)		
1908	7 July	129,000	1917	25 September	89,125
(4)	26 July	65,000	(2)	27 October	116,000
	29 July	193,000			
	28 August	52,000	1919	25 July	73,000
			(2)	28 July	64,000
1909	24 August	51,000			
(3)	31 August	51,000	1920	23 July	129,000
	3 September	64,000	(2)	2 August	50,200

TABLE III—*contd.*

Year	Date	Discharge (cusecs)	Year	Date	Discharge (cusecs)
1921	3 August	68,500	1928	28 August	57,774
(3)	13 August	64,000	(2)	2 September	64,000
	22 August	57,400			
			1929	16 August	61,864
1922	26 July	75,150	(1)		
(1)					
			1930	9 April	61,170
1923	16 August	52,867	(4)	11 July	110,625
(1)				3 August	63,750
				9 August	51,500
1924	25 July	116,120			
(2)	28 August	89,245	1932	18 July	168,630
			(3)	23 July	71,570
				27 July	51,126
1925	11 August	94,500			
(2)	13 August	94,500	1933	9 July	101,900
			(5)	22 July	68,686
				23 July	65,168
1926	28 July	61,400		30 July	85,571
(3)	1 August	52,402		14 August	85,100
	30 August	145,000			
1927	4 August	51,134	1936	22 August	192,920
(1)			(2)	23 August	90,820

Total number recorded from 1901 to 1920 = 36

Total number above 100,000 cusecs = 8

Total number from 1921 to 1936 = 30

Total number above 100,000 cusecs = 6

This division into two periods of 20 and 16 years showed that there is no noticeable increase either in the number of floods or in their volume within recent years.

Some difficulty was experienced in averaging the figures for earlier years, as the gauge discharge relations were not accurately known. A preliminary analysis was made by noting the number of days in each of the four months from November to February when the supply fell below 2,000 cusecs, and there seemed to be an indication that the number of such days was going up within the last 12 years. But the unreliability of the earlier figures made it difficult to say if the change was real.

The average discharges for the last 20 years were next computed, any values above the usual run of the month being disregarded. These are given in the following table :—

Year	November	December	January	February
1916-17	2,549	2,173	1,931	1,819
1917-18	4,237	2,475	2,361	2,060
1918-19	2,844	2,621	3,340	3,956
1919-20	2,397	2,198	1,998	3,270
1920-21	2,112	1,748	1,976	2,362
1921-22	2,366	2,370	2,954	4,000
1922-23	2,633	2,130	2,972	4,382
1923-24	2,432	2,318	2,211	3,900
1924-25	2,748	2,422	2,445	3,326
1925-26	3,272	2,099	1,852	1,706
1926-27	2,902	1,822	1,682	2,584
1927-28	2,079	1,658	1,939	4,184
1928-29	2,300	2,798	2,751	4,013
1929-30	2,475	4,078	4,200	5,500
1930-31	2,037	1,567	2,073	2,900
1931-32	2,363	1,706	1,705	1,927
1932-33	1,896	1,785	1,822	2,880
1933-34	2,937	2,048	2,249	1,322
1934-35	1,923	1,822	3,051	4,658
1935-36	2,210	1,808	1,692	1,981

The record was too short for any conclusions to be drawn with safety, but it seemed that while a tendency was not established, the winter supplies need to be watched.

The rainfall at Dalhousie was studied both from daily and monthly values. The conclusions drawn from the analysis were :

(*a*) The total monsoon rainfall appears to be steady during the last 14 years. The winter rainfall decreased from 1906 to 1928, after which it has increased. But as the whole period under study amounts to less than the usually accepted cycle of 35 years, these changes which are small are not significant, (*b*) The records do not show that, within these 35 years, there is any trend towards increase or decrease of precipitation in any individual month.

(*c*) There are, on an average, three to four days during the monsoon months every year when the daily rainfall exceeds 3 in., and about three days in winter months when it exceeds 2 in. The heaviest recorded rainfall (9·8 in.) is for 7 July 1908. This month also recorded the heaviest total rainfall (43·4 in.) and the heaviest rainfall for any four successive days (16·2 in.) for July 26-29.

The inter-relation of floods and rainfall led to the question : Is every flood preceded by unusually heavy rainfall ; and conversely, is continuously heavy rainfall followed invariably by a flood ?

Some of the heavier floods and the preceding rainfall are shown below :—

Date	Discharge (cusecs)	Rainfall (in.)
29 July 1908	193,000	4·1 (26th), 5·1 (28th) 6·4 (29th)
22 August 1936	193,000	6·9 (22nd)
18 July 1932	168,630	3·0 (16th), 3·1 (18th)
10 August 1903	190,000	1·1 (7th), 1·7 (8th) 1·0 (9th), 1·8 (10th)
23 July 1920	129,000	3·2 (23rd)
7 July 1908	129,000	9·8 (7th)
30 August 1926	145,000	1·1 (29th), 2·5 (30th)
29 July 1910	116,000	1·8 (28th), 3·6 (29th)

The figures for some of the moderate floods registered in succession are shown below :—

Date	Discharge (cusecs)	Rainfall (in.)
22 July 1914	51,500	1·0 (20th), 2·1 (21st), 5·2 (22nd)
27 July 1914	75,300	1·8 (23rd)
28 July 1914	83,520	2·5 (27th)
29 July 1914	51,500	2·1 (28th)
30 July 1914	51,500	5·3 (29th)
14 September 1906	73,000	2·8 (14th)
15 September 1906	83,000	1·9 (15th)
16 September 1906	135,000	3·6 (16th)
11 August 1925	94,500	1·2 (9th), 1·5 (10th), 3·2 (11th)
13 August 1925	94,500	3·3 (12th), 3·2 (13th)
22 July 1933	68,686	2·7 (22nd)
23 July 1933	65,168	0·3 (23rd)
22 August 1936	193,000	6·9 (22nd)
23 August 1936	90,820	2·2 (23rd)

It is thus seen that a heavy flood is usually due either to heavy rainfall on a single day or to moderate rainfall on a successive number of days.

The moderate floods also behave similarly and while the floods in 1933 are heavier for comparatively less rainfall, this may be probably due to a greater intensity of precipitation within fewer hours.

Some of the heavier showers were next examined to see if they were followed by floods :—

Date	Rainfall (in.)	Discharge (cusecs)
22 July 1904	6·9	Rose from 15,000 to 35,000
11 September 1905	4·5	Rose from 11,000 (10th) to 17,000 (11th), 24,000 (12th) and 85,000 (13th)
12 September 1905	3·5	
13 September 1905	4·1	
28 July 1908	5·1	15,000 (27th), 17,000 (28th), 193,000 (29th)
29 July 1908	6·4	
16 August 1909	7·3	Gauge rose by 1·8 ft.
24 August 1909	6·9	Gauge rose by 6·0 ft. (21,000 to 64,000)
20 June 1917	4·0	Rose from 8,400 (19th) to 30,000 (20th and 21st)
21 June 1917	3·1	
11 August 1925	3·2	94,500
12 August 1925	3·3	34,200
13 August 1925	3·2	94,500
16 July 1932	3·0	37,000 (16th)
18 July 1932	3·1	169,000 (18th)
13 August 1935	5·0	22,000 (12th)
22 August 1936	6·9	193,000 (22nd)
23 August 1936	2·2	90,820 (23rd)

The deductions made were :

(1) The various falls are not strictly comparable, as the intensity of run-off and time-lag have not been allowed for, the distribution of the daily rainfall over all the 24 hours not being known.

(2) There are probably a few showers which would not affect the discharge appreciably, but on the whole the correspondence is satisfactory.

Although it has been impossible to detect any increase in the size or number of floods during the period under examination, this does not mean that such an increase has not taken place. It appears probable that the denudation had reached its maximum in the period prior to the data examined. It is unfortunate that records of an earlier date are not available.

VIII. ADMINISTRATIVE

To conclude this paper with the statement that the object of irrigation is the development of agriculture may seem absurd until it is realized that two separate departments are concerned with the use of the water. The two departments, the Irrigation Branch of the Revenue Ministry and the Agricultural Department of the Development Ministry, are self contained, and each considers the subject from its own particular point of view. The income of the province is the special concern of the Revenue Ministry and to this income the Irrigation Branch is one of its main contributors. The main object of the Irrigation Branch is therefore to produce the greatest possible revenue per cusec of available water. This involves the spreading of the water for irrigation purposes over the greatest possible area. The main object of the Agricultural Department, since it considers the individual zemindar, is the production of the maximum yields of crops per acre. This may involve a larger number of waterings per acre or it may be necessary to grow those varieties of the crops which have long growing periods. Both of these causes necessitate the use of the available water on a relatively small area. Since the basis of assessment is the area under crop and not the volume of water used, it follows that the objects of the two departments are diametrically opposed. It has also been indicated in the section dealing with land deterioration that the increase in the cultivated area without a corresponding increase in the water supply may be one of the factors causing soil deterioration. It will be seen therefore that a major difficulty in obtaining the optimum effect from an irrigation system consists in devising some means of reconciling the opposing objects of the two departments. It has been suggested that since irrigation is for the benefit of the people of the Province, its main object should not be the production of revenue. Where mineral resources are large and industries can be established, this view may hold. When the Province, however, by nature must be mainly agricultural, no alternative source of revenue appears to be available, and therefore it seems likely that the Irrigation Branch will continue to be mainly a revenue-earning department.

REFERENCES

Blench, T. (1939). *Report on studies of seepage losses from canals* (Note submitted to the Central Board of Irrigation, India, for the Research Committee Meeting in July 1939)

Bligh, W. G. (1927). *The practical design of irrigation works* (revised by F. W. Woods) : Constable & Co., Ltd., London

Bose, N. K. and Malhotra, J. K. (1939). *Pb. Irrig. Res. Inst. Res. Pub.* (In Press)

Chanan Singh, Luthra, H. R. and Vaidhianathan, V. I. (1937) *Pub. Irrig. Res. Inst. Res. Pb.* **5**, No. 9

Gorie, R. M. (1939). *Ind. For., May*

Holland and Christie, (1909 & 1923). *Rec. Geol. Sur. (India)* **38**, 54

Kennedy, R. G. (1896). *Pub. Irrig. Branch Paper* No. 7

Khosla, A. N., Bose, N. K., and McKenzie Taylor, E. (1936). *Central Bd. Irrig.* (*India*) *Pub.* No. **12**

Lacey, G. (1930). *Inst. Civil Eng. Paper* No. **4736**

Lindley, E. S. (1928) *Pb. Irrig. Br. Paper* No. **31-A**

Malhotra, J. K. (1938). *An investigation of the rise of water-table in the lower part of the Rechna Doab* (Note submitted to the Chief Engineer, Irrigation Branch, Punjab)

———— (1936, 37). *An investigation of the seepage losses in Jhang Branch and Kasur Branch Lower* (Notes submitted to the Chief Engineer, Irrigation Branch, Punjab)

McKenzie Taylor, E. (1935). *Report on the possible lowering of the water-table in the United Provinces as a result of tube-well pumping*: Supdt., Printing and Stationery, U. P., Allahabad

———— (1937). *Ann. Rep. Pb. Irrig. Res. Inst. for the year ending April 1937*

———— (1938). *Ann. Rep. Pb. Irrig. Res. Inst. for the year ending April 1938*

McKenzie Taylor, E., Malhotra, J. K. and Mehta, M. L. (1933). *Pb. Irrig. Res. Inst. Res. Pub.* **1**, No. 4

Mehta, M. L. (1938). *Ann. Rep. Pb. Irrig. Res. Inst. for the year ending April 1938*

Puri A. N. (1935). *Ann. Rep. Pb. Irrig. Res. Inst. for the year ending April 1935*

———— (1937). *Ann. Rep. Pb. Irrig. Res. Inst. for the year ending April 1937*

Vaidhianathan, V. I. (1933). *Pb. Irrig. Res. Inst. Res. Pub.* **5**, No. **1**

————(1938). *Ann. Rep. Pub. Irrig. Res. Inst. for the year ending April 1938*

Wilsdon, B. H. and Bose, N. K. (1934). *Pb. Irrig. Res. Inst. Res. Pub.* **6**, No. 1

Wilsdon, B. H. and Sarathy, R. P.(1927-28). *Pb. Irrig. Res. Inst. Res. Pub.* **1**, Nos. **1**, **2**

A NEW TYPE OF VARIEGATION IN RICE*

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(With Plate XI and one text-figure)

INTRODUCTION AND REVIEW OF LITERATURE

SEVERAL types of chlorophyll deficiencies in rice have been described and genetically studied. They include both unicoloured and variegated forms which are inherited either as a result of the operation of genetic factors or as a result of the transmission of abnormal plastids contained in the cytoplasm of the egg-cells. All the unicoloured types, so far studied, are known to be inherited in a mendelian fashion ; they are usually recessive to normal green and are controlled by one or more pairs of factors. Thus Morinaga [1927], Ramiah [1930], Kadam and Patanker [1934], Codd [1934] and others have shown that one, two or three pairs of recessive factors when present in the homozygous condition produce albinos. Other unicoloured seedlings variously described as virescent, xantha, lutescent, etc., have also been shown to be inherited on mendelian lines [Ramiah and Ramanujam, 1935].

Variegated plants may be divided into two classes : those that exhibit variegation in the early seedling stages, becoming green later on, and those that continue to show the variegation up to maturity. Among the former may be mentioned the striped seedlings reported by Ramiah and Ramanujam [1935] and Jodon [1940] ; these are also inherited on mendelian lines. Variegated plants described by Kondo *et al.* [quoted by Imai, 1928], Morinaga [1932], Mitra and Ganguli [1934], Ramiah and Ramanujam [1935], and Oryozi [1936] belong to the latter class. In most of the above-mentioned cases the variegation occurs in coarse, longitudinal stripes of green and yellow or green and white on the stem, foliage, leaves and glumes ; all the tillers of the plant may be variegated or occasionally a few green tillers may be found on a variegated plant, or *vice versa*. In some cases the variegation may consist of fine stripes of white and green and individuals of this type are variegated in all their tillers. Apparently the type of variegation described by Mitra and Ganguli [1934] belongs to this class.

As regards inheritance, variegated plants are inherited either bi-parentally or maternally. Mitra and Ganguli [1934] obtained pure white-striped plants which behaved as a simple recessive to normal green. Morinaga [1932] has also recorded the simple inheritance of a few variegated forms. The variegated plants described by the other authors all show maternal inheritance. These may again be divided into two classes in regard to hereditary type : in

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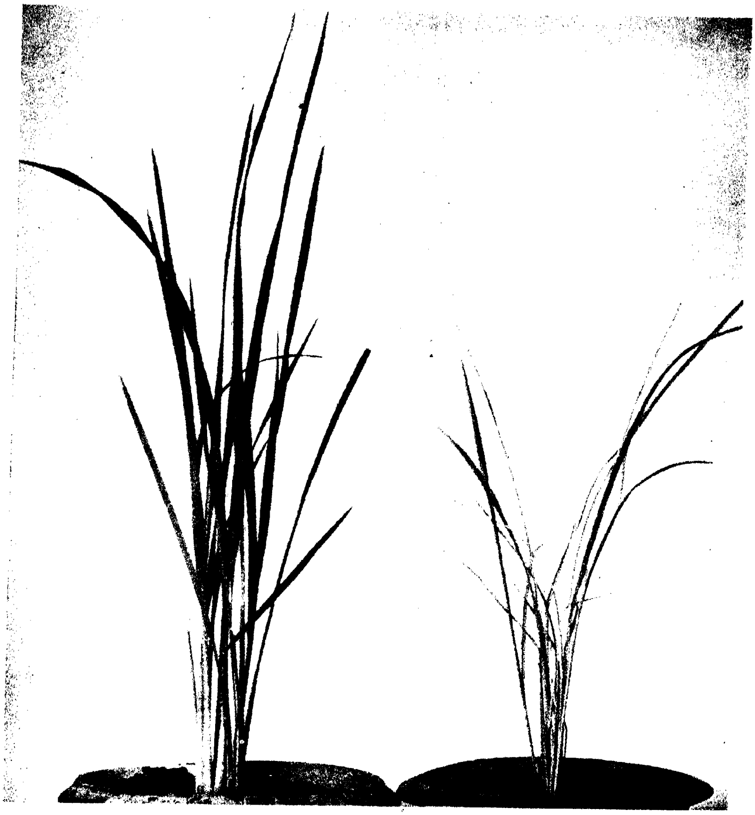
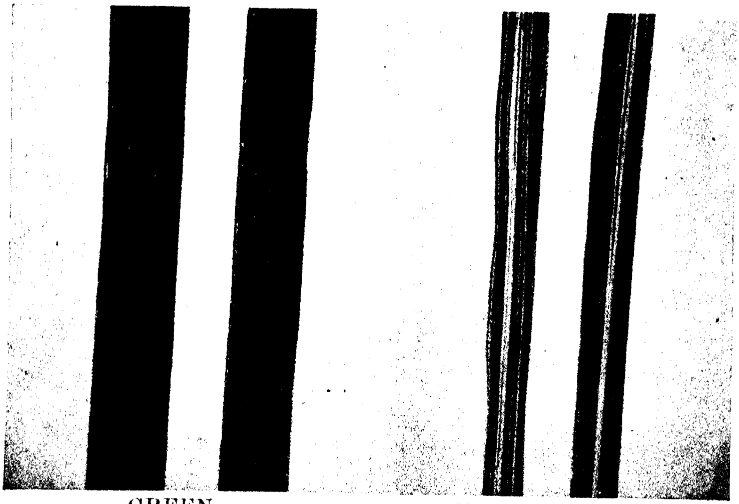


FIG. 1 Green and variegated seedlings showing stripes in the latter



one case variegated plants appear in great numbers in the progeny of these plants, and in the other few or no variegateds are obtained, but segregation produces green and white seedlings from green-and-white variegated plants and green and yellow from green-and-yellow variegated plants; the white and yellow seedlings die after a few days in the nursery. The appearance of a large number of variegated plants in the progenies of such plants is explained by Imai [1928] to be due to the habitual mutability of the plastids, entirely out of control of genetic factors.

It is obvious from the foregoing review of literature that inheritance of variegation in rice is either maternal or bi-parental. In this paper a new type of variegation is described which combines both these types of inheritance.

DESCRIPTION AND BREEDING BEHAVIOUR OF THE VARIEGATED PLANT

In the year 1934-35 one variegated seedling was noticed in the seedbed of the rice variety Imperial Pusa 27 at the Botanical Section in Pusa. The leaves of this plant showed fine longitudinal stripes of green and white, and this striping was noticed to persist in all the tillers of the plant even at maturity (Plate XI, figs. 1 and 2). The glumes were mostly white or occasionally striped. This plant differed from those described by Ramiah and Ramanujam [1935] in that the variegation was not as coarse and variable as in the latter, and, furthermore, no green tillers were produced on this plant. The plant was weaker than its sisters, the leaves were narrower and rolled inwards from the margin and seed-setting was poor. The seeds of this plant, when sown the following year, gave rise to variegated plants resembling the mother and albinos which died a few days after. The progenies of some of these variegated plants were studied in 1937-38 and the segregations observed are given below :–

Variegated plant No.	Nature of progeny	
	Variegated	Albino
1 . . .	18	17
2 . . .	31	42
3 . . .	78	41
4 . . .	23	8
5 . . .	3	1
6 . . .	27	30
7 . . .	60	47
8 . . .	70	65
9 . . .	39	12
10 . . .	26	22
11 . . .	38	26
12 . . .	5	31
13 . . .	23	26
14 . . .	25	16
15 . . .	84	31
16 . . .	33	19
17 . . .	16	25
18 . . .	4	2
19 . . .	19	12
20 . . .	20	7
21 . . .	52	17
22 . . .	18	8
23 . . .	8	4
24 . . .	60	30
25 . . .	13	9
	795	548

It is seen from the above table that the variegated plants give rise to variegateds and albinos in varying proportions, and that no green plants are present in any progeny. In this respect the variegated plants resembled the maternally inherited types described by Kondo, the only difference being that in the latter case a few green plants were also found to occur in the progenies of variegated plants.

In the following year (1938-39), several variegated plants were again grown and their progenies were found to segregate into variegateds and whites in varying proportions as on previous occasions. One plant, however, gave rise to a few greens besides whites and variegateds. One hundred seeds of one of these green plants were sown in 1939-40 and the resulting seedlings showed a segregation of 70 green to 20 variegated ; there was not a single albino present. This segregation seemed to indicate a monohybrid ratio with variegation as recessive to green.

To confirm these results eleven green plants from this segregating culture were selected at random and crossed reciprocally with variegated plants during 1939-40. The setting in crosses and the variegated plants was poor as the latter is normally a poor setter. The seeds from the parents and the crosses were sown in 1940-41. The following are the results :—

Segregation in the progenies of green plants

Culture No.	Green	Variegated	Total	Remarks
G 20	98	*Nil*	98	
G 254	95	*Nil*	95	One hundred seeds in each culture were sown.
G 134	98	*Nil*	98	
Total .	201	..	300	
G 251	80	18	98	
G 124	73	20	93	
G 171	78	20	98	
G 70	70	29	99	
G 128	77	22	99	
G 131	76	21	97	
G 23	70	29	99	
G 230	66	25	91	
Total .	590	184	774	
Calculated 3 : 1	580	194	774	

P between 0.5 and 0.3. Therefore the fit is good.

It is seen from the above table that out of 11 families in the F_3 (assuming the original green plant to be a natural cross) three were pure for green and eight segregated into green and variegated in the ratio of 3 : 1. These figures amply confirm the earlier finding that variegation itself is a simple recessive to normal green.

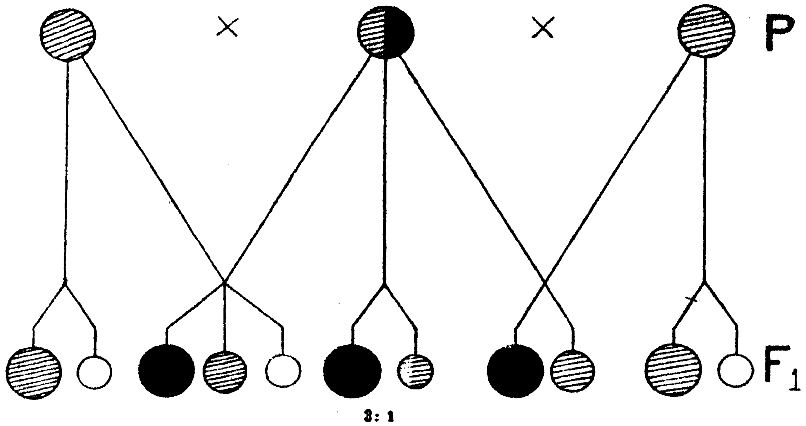
The variegated plants used as parents in the artificial crosses set very few seeds, and they, on sowing, gave rise to striped and white plants as expected.

Segregation in artificial cross progenies

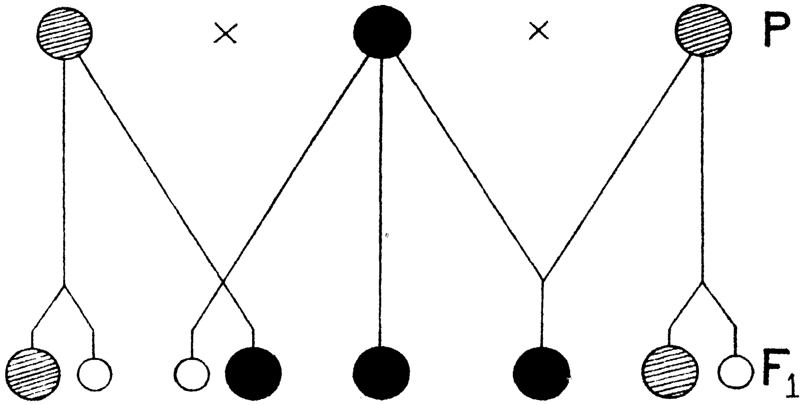
Parents of the crosses	No. of seeds obtained from the cross	No. of seeds germinated	Nature of progeny		
			Green	Variegated	White
Variegated 12 × homozygous green 254	1	1	1	..	..
,, 1 × ,, 20	2	1	1	..	..
,, 16 × ,, 134	1	..	..	..	..
Total	4	2	2	..	..
Variegated 15 × heterozygous green 70	3	3	3	..	..
,, 21 × ,, 131	8	6	2	3	1
,, 1 × ,, 23	6	2	2	..	..
,, 10 × ,, 128	2	..	..	..	..
,, 15 × ,, 131	1	1	..	1	..
,, 27 × ,, 251	6	6	2	..	4
Total	26	18	9	4	5
Heterozygous green 171 × variegated 1	4	4	3	1	..
,, 230 × ,, 1	4	..	..	..	..
Total	8	4	3	1	..

Unfortunately, in the above crosses the seed-setting was poor and only very few F_1 plants were obtained. Nevertheless an examination of the progenies obtained from these crosses confirms the fact that variegation itself is a genetic character being inherited as a simple recessive to green, while albinism is transmitted only maternally.

The expected behaviour of the parents and crosses on the basis of this combined inheritance may be schematically represented as in Fig. 1.



Heterozygous green × Variegated (reciprocal)



Homozygous green × Variegated (reciprocal)

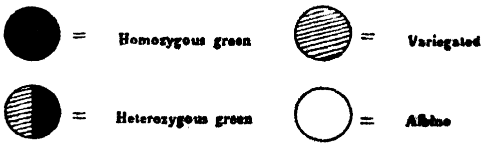


Fig. 1. Expected behaviour of parents and crosses

When the actual data obtained are examined in the light of this scheme, it is found that the expectations are mostly fulfilled, except in the case of crosses between homozygous green × variegated which, unfortunately, did not set any seed.

DISCUSSION

The important point to notice about the variegation described here is that, unlike the case in coarsely variegated plants, its pattern is fairly constant through successive generations ; it does not produce any wholly green tillers. The only variegated type that might be related to this is the one described by Mitra and Ganguli, but in the latter case the inheritance is governed by a ' pattern gene ' and pure variegateds are obtained. The only reported case, as far as we know, of a variegation which is inherited as in the present case is that reported in barley by Sô in 1921 (quoted by Imai [1928]). This variegated race is described to have fine white stripes on foliage and ears. Sô studied thoroughly the genetic behaviour of variegation in this variety and found that albinism was transmitted only maternally, while variegation itself was a mendelian recessive to green. On the basis of these experimental facts he developed a theory to account for the special hereditary bevahiour of his barley. According to him the variegated character, which is transmitted as a recessive, is not due to a pattern gene since the white parts of stripes are due to the distribution of white plastids which have changed their quality permanently and, therefore, are able to give rise to albinos in the progeny of variegated plants. ' The variegation is, therefore, produced by a factor which alters at times the essential quality of the plastids from normal green to colourless '. The plastid mutation that is observed in various other plants is due to sporadic events, but in the case of this barley and the present case in rice, the plastid mutation repeats itself so frequently in the course of the development of the plant body that not a single individual or leaf or even an ear is free from variegation. This presumably accounts for the constancy of this character from generation to generation.

Although some of the results of crosses are still incomplete, and we are continuing the investigation, the results so far obtained amply confirm the peculiar nature of inheritance of variegation reported in this paper.

SUMMARY

A new type of variegation is described. The variegated plants have fine stripes of green and white on the stem, foliage and glumes. They are weaker than the green plants, with narrower leaves and poorer seed-setting.

The variegated plants, when selfed, give rise to variegated plants and albinos in varying proportions ; but when crossed reciprocally with green plants, give rise to normal greens in the F_1 generation. Heterozygous green plants segregate into greens and variegateds in the ratio of 3 : 1 ; no albinos are present in the progenies.

The breeding behaviour of variegated plants in selfed and crossed progenies has shown that variegation is a mendelian recessive to green, but albinism is transmitted only maternally.

REFERENCES

Codd, L. E. W. (1935). *J. Hered.* **26**, 85-7

Imai, Y. (1928). *Genetics* **13**, 544-62

Kadam, B. S. and Patanker, V. K. (1934). *Poona Agric. Coll. Mag.* **26**, 10-6

Mitra, S. K. and Ganguli, P. M. (1934). *Ind. J. Agric. Sci.* **4**, 537-45

Morinaga, S. (1927). *Bot. Mag. (Tokyo)* **41**, 575-6

Morinaga, T. (1932). *Bot. Mag. (Tokyo)* **46**, 202-7 [Abst. *Jap. J. Bot.* (1932) **6**, 44-5]

Oryozi, G. (1936). *J. Taihoku Soc. Agric. and Forest.* **1**, 231-96 [Abst. *Jap. J. Bot.* **9**, 18]

Ramiah, K. (1930). *Mem. Dep. Agric. India (Bot. Ser.)* **18**, 211-27

Ramiah, K. and Ramanujam, S. (1935). *Proc. Ind. Acad. Sci.* **2**, 343-68

FIBRE-MATURITY IN RELATION TO GROUP-LENGTHS OF SOME COTTONS GROWN IN THE PUNJAB

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I. Introduction

THE spinning performance of a cotton depends upon the physical characters of the individual fibres composing it, such as length, fineness, width, strength and maturity. The importance of these characters in assessing the value of a cotton is realized when it is brought out that for Indian cottons [Turner and Venkataraman, 1933] the total correlation coefficients between the highest standard warp counts (H. S. W. C.) and each of the first four of these characters are :

H. S. W. C. and mean fibre-length	+0·87
H. S. W. C. and mean fibre-weight per unit length . .	—0·80
H. S. W. C. and mean fibre-width	—0·69
H. S. W. C. and mean fibre-strength	—0·33

and are all of them significant for $P \ngtr 0{\cdot}05$. For 32 samples of Indian cottons Gulati and Ahmad [1935] find the correlation coefficient between the H. S. W. C. and the percentage of mature fibres to be —0·07. Examining further they find that, for comparatively short-staple cottons, higher spinning performance is associated with lower maturity percentage and that, for medium-staple cottons, higher fibre-maturity goes hand-in-hand with better spinning performance. The correlation coefficient between the percentage of mature fibres and H. S. W. C. for the first group comes out to be —0·66, while that for the second group is found to be +0·56. The coefficient for the first group bears a negative sign while that for the second group is positive. Thus 'in a batch of cottons containing short-staple and medium-staple samples the opposite trends cancel one another, resulting in an insignificant correlation between the two attributes'.

This conclusion is very important as it contains the germ of the idea on which some previous studies as well as the present one in the technology of Indian cottons are based. Any sample of cotton contains fibres of different lengths and it is known that the physical characters of fibres of different lengths even of the same cotton may vary from one group-length to another. Turner [1929] concluded that in some cottons differences did exist in the fibre-weight per unit length for different lengths of fibre. Iyengar and Turner [1930], from a study of 18 standard Indian cottons, including all the important commercial types, concluded that the fibre-weight per unit length was not the same for different lengths of fibre of a given cotton. Nanjundayya and Ahmad [1938] found that the mean breaking load and fibre-weight per unit length decreased with an increase in group-length for all the Indian cottons excepting N 14 which behaved somewhat erratically. Iyengar [1939] concluded that the mean and maximum ribbon-width and the swollen diameter generally decreased with increase of length and that variations in the number of convolutions per unit length and in the maturity of fibres with respect to length were different in different cottons.

The importance of the study of fibre-maturity in a cotton has been stressed by Gulati and Ahmad [1935], and it is seen from the above summary of previous work that variations in fibre-maturity with group-length have not systematically been studied heretofore. The work described in the present paper was undertaken with the object of studying these variations in the Punjab cottons.

II. MATERIAL

The material for this work was drawn from the bulk samples of the seed multiplication area at the Cotton Research Farm, Risalewala, Lyallpur, in 1937. The varieties were :

Punjab-*desi*	39 Mollisoni
New crosses	Jubilee
Punjab-American	289F, 289F/43, 289F/K25, 4F, LSS, 47F, 58F, 100F and 104F

The sliver for each variety was obtained by the usual sampling methods and constituted the working sample.

III. EXPERIMENTAL

Each variety was tested for quality of the bulk sample with reference to the following fibre characters :—

(*a*) Mean length

(*b*) Modal length

(*c*) Fibre-length irregularity percentage

(*d*) Mean fibre-weight per unit length

and (*e*) Immaturity.

The mean length was determined with Balls Sledge Sorter and the modal length and fibre-length irregularity percentage were derived from the Balls sorter distribution by the methods described by Ahmad [1932]. The mean fibre-weight per unit length was obtained after the whole-fibre method and fibre immaturity was determined by the technique described by Gulati and Ahmad [1935] using the 'maturity slides' devised by Ahmad and Gulati [1936]. The values thus obtained for the bulk sample are given in Appendix I.

The sliver of each variety was then fed into the feed-box of the Balls Sledge sorter and the fibres laid on the one-way plush and collected in groups of ⅛th of an inch as is usually done in a Balls sorter test. By repeating the process, sufficient quantity of fibre was collected in each group-length. The bundle of fibres in each group-length was hand-drafted, cleaned and combined to give a hand-made sliver. The different slivers were kept separate from one another in paper wrappers with distinct markings indicating the group-lengths. The fibres in each group-length were tested for maturity. For this purpose, it was found that the 'maturity slides' of Ahmad and Gulati were very convenient for mounting fibres in group-lengths of 5/8 inch and above. For fibres in group-lengths of 4/8 inch and lower, the following method was improvised :

A microscope-slide was sparsely wetted with water and the fibres, taken individually from the sliver with a pair of forceps, were arranged in the middle part of the slide as nearly parallel to one another as possible and with one of their ends approximately along a line. After placing a sufficient number of fibres on the slide, a cover-glass slip, with a drop of 18 per cent caustic soda solution adhering to it, was slid on to the slide such that the fibres were held between the slide and the cover-slip by the caustic soda solution. Fifteen minutes later the slide was examined for maturity.

This technique was also adopted for fibres of the longest group-length of each variety as there were only a few fibres in that group.

The number of fibres tested for maturity was not less than 500 [Gulati and Ahmad, 1935] in each group-length excepting the end ones, where, due to a deficiency in the number of fibres, all the fibres collected were tested. The results of these tests are given in Appendix II, which contains both the actual numbers and percentages of mature, half-mature and immature fibres as well as the total number of fibres tested in each group-length of the different varieties.

IV. DISCUSSION OF RESULTS

As the percentage of mature fibres in a sample determines, to some extent the behaviour of the sample, during spinning processes, the statistical analysis of the results was carried out on the percentage of mature fibres in each group-length. To study the influence of the half-mature and the immature fibres present in each group-length, the statistical analysis was repeated on the 'maturity coefficient' in each group-length of these varieties. This coefficient was derived according to the formula given by Peirce and Lord [1934] and served to express the result of the maturity count as a single quantity suited to quantitative analysis. (The percentage of mature fibres and the maturity coefficient are collectively referred to hereinafter as maturity 'terms' for simplicity.)

(*a*) The number of *desi* cottons tested was only two. Of these, 39 Mollisoni is an indigenous cotton and Jubilee is a new cross between the Punjab-Mollisoni and the Chinese Million Dollar. No general conclusions could be drawn from such meagre data, but a study of the results showed that, in 39 Mollisoni, both the percentage of mature fibres and the maturity coefficient remained almost constant in all the group-lengths with the exception of the first group (i.e. 2/8 inch), while in Jubilee, both these terms showed an increase with an increase in the group-length.

(*b*) The other varieties were all Punjab-American (P-A) cottons, with staple-lengths ranging between 2·21 and 2·43 cm. with the exception of P-A 4F, which had a staple-length of 1·92 cm. and was not, therefore, included in the analysis.

TABLE I

Maturity terms

Group length	289F	289F/ 43	289F/ K 25	58F	100 F	104F	L S S	47F	Average
(a) Percentage of mature fibres									
3	76·2	47·5	43·2	69·7	64·3	47·0	62·5	58·9	58·66
4	75·0	38·6	39·6	65·0	57·7	41·0	61·7	54·6	54·15
5	62·9	42·6	40·0	62·3	48·5	51·6	57·9	50·7	52·06
6	67·1	39·1	35·6	67·6	58·8	50·3	54·1	60·5	54·14
7	71·4	35·7	31·1	66·4	57·2	45·6	51·3	56·3	51·88
8	69·6	43·5	35·8	73·4	54·4	52·8	53·4	48·1	53·88
9	67·4	47·3	47·8	78·0	57·6	47·8	52·4	47·6	55·74
10	70·8	50·2	43·6	76·9	63·4	60·0	69·2	59·2	61·66
Average	70·05	43·06	39·59	69·91	57·74	49·51	57·81	54·49	55·27
(b) Maturity coefficient									
3	0·9198	0·8071	0·7797	0·8971	0·8717	0·7958	0·8663	0·8561	0·8492
4	0·9234	0·7710	0·7844	0·8813	0·8586	0·7718	0·8637	0·8492	0·8379
5	0·8814	0·7896	0·7539	0·8853	0·8145	0·8128	0·8478	0·8374	0·8278
6	0·8940	0·7722	0·7620	0·9023	0·8574	0·8167	0·8437	0·8606	0·8386
7	0·9043	0·7733	0·7547	0·9050	0·8606	0·8048	0·8387	0·8562	0·8372
8	0·9091	0·8055	0·7861	0·9219	0·8619	0·8358	0·8419	0·8354	0·8497
9	0·9027	0·8209	0·8088	0·9346	0·8744	0·8338	0·8584	0·8304	0·8580
10	0·9183	0·8437	0·8165	0·9334	0·8918	0·8764	0·9018	0·8763	0·8823
Average	0·9066	0·7979	0·7808	0·9076	0·8614	0·8185	0·8578	0·8502	0·8476
(c) Maturity index									
3	0·8530	0·6554	0·6116	0·8124	0·7694	0·6395	0·7593	0·7398	0·7300
	0·8562	0·5923	0·6119	0·7834	0·7410	0·5974	0·7544	0·7233	0·7075
5	0·7801	0·6238	0·5718	0·7843	0·6669	0·6697	0·7270	0·7011	0·6906
6	0·8039	0·5948	0·5754	0·8158	0·7412	0·6728	0·7152	0·7483	0·7084
7	0·8246	0·5905	0·5580	0·8173	0·7428	0·6490	0·7038	0·7354	0·7027
8	0·8281	0·6465	0·6078	0·8515	0·7399	0·7023	0·7116	0·6941	0·7227
9	0·8159	0·6733	0·6828	0·8700	0·7619	0·6915	0·7377	0·6866	0·7407
10	0·8423	0·7087	0·6615	0·8727	0·7948	0·7686	0·8178	0·7671	0·7792
Average	0·8255	0·6357	0·6101	0·8267	0·7447	0·6739	0·7409	0·7245	0·7227

TABLE II

Analysis of variance

Source of variation	D. F.	Sum of squares	Mean square	F	Remarks
		(a) Percentage of mature fibres			
Varieties . .	7	6993·04	999·01	51·205	H. S.
Length-grades . .	7	631·11	90·16	4·621	H. S.
Residual . .	49	955·99	19·51	..	..
Total .	63	8580·14	..	..	..
		(b) Maturity coefficient			
Varieties . .	7	0·121352	0·017336	71·17	H. S.
Length-grades . .	7	0·015925	0·002275	9·34	H. S.
Residual . .	49	0·011934	0·000243$_6$	..	..
Total .	63	0·149211	..	..	..
		(c) Maturity index			
Varieties . .	7	0·358720	0·051246	64·14	H. S.
Length-grades . .	7	0·043494	0·006213	7·776	H. S.
Residual . .	49	0·039130	0·000799	..	..
Total .	63	0·441344	..	..	..

In the six varieties, 289F, 289F/43, 289F/K25, 58F, 100F, and 104F, the percentages by weight of fibres in the two pairs of end-groups, viz. the 2/8, 3/8, and the 10/8, 11/8 inch groups, as determined with the Balls sorter, were very small. Therefore, the average of the maturity terms of the first pair of end-groups was taken as representative of the 3/8 inch group and that of the second pair as representative of the 10/8 inch group. The varieties L S S and 47F did not have fibres longer than 10/8 inches in length. Hence the maturity terms only in the first pair, viz. 2/8 and 3/8 inch groups, were averaged, the average being considered as belonging to the 3/8 inch group. The values in the 10/8 inch group remained unaltered. The values of the maturity terms thus formed are compiled in Tables I (*a*) and (*b*) and the analysis of variance is brought out in Tables II (*a*) and (*b*) respectively.

The analysis of variance applied to these results showed that the mean square due to varieties was highly significant for both the maturity terms as was naturally to be expected. The mean square due to length-grades was also highly significant showing that, in addition to differences in fibre-maturity brought about by differences in variety, there was an intrinsic variation in fibre maturity with a variation in the length of the fibre. This latter variation could best be studied by fitting a curve between the group-length and the corresponding average maturity term. Parabolic regression equations were fitted by Fisher's covariance-matrix method which was described in detail by Koshal [1934]. The utility of this method is evident from the fact that the same covariance-matrix has been used for deriving the equations I and II for the percentage of mature fibres and the maturity coefficient respectively. Moreover, it provides material for the calculation of the standard error of the regression coefficients.

The two regression equations were :

$$M = 75{\cdot}734 - 7{\cdot}681\, l + 0{\cdot}620\, l^2 \quad . \quad . \quad . \quad . \quad . \quad . \qquad \text{I}$$

$$\text{and } C = 0{\cdot}9061 - 0{\cdot}02661\, l + 0{\cdot}002410\, l^2 \quad . \quad . \quad . \quad . \quad . \qquad \text{II}$$

where M is the percentage of mature fibres ;

C is the maturity coefficient [Peirce and Lord, 1931] ; and

l is the length-grade in units of one-eighth of an inch.

The standard errors of the regression coefficients were :—

$$\begin{array}{ll} & \left.\begin{array}{l} -7{\cdot}681 \ \pm 1{\cdot}284 \\ +0{\cdot}620 \ \pm 0{\cdot}0975 \end{array}\right\} \text{equation I ;} \\ \text{and} & \left.\begin{array}{l} -0{\cdot}0266 \ \pm 0{\cdot}0041 \\ +0{\cdot}00241 \pm 0{\cdot}00031 \end{array}\right\} \text{equation II.} \end{array}$$

TABLE III

Further analysis of variance

Source of variation	D. F.	Sum of squares	Mean square	F	Remarks
		(a) Percentage of mature fibres			
Parabolic regression .	2	566·36	283·18	..	..
Deviations from regression	5	64·75	12·95	0·66	N. S.
Total (length-grade)	7	631·11	..	..	..
		(b) Maturity coefficient			
Parabolic regression .	2	0·015293	0·007647	..	..
Deviations from regression	5	0·000632	0·0001264	0·52	N. S.
Total (length-grade)	7	0·015925	..	..	..
		(c) Maturity index			
Parabolic regression .	2	0·041694	0·020847	..	..
Deviations from regression	5	0·001800	0·000360	0·45	N. S.
Total (length-grade)	7	0·043494	..	..	..

Regression equations :

$$M = 75\cdot734 - 7\cdot681\, l + 0\cdot620\, l^2 \quad . \quad . \quad . \quad . \quad . \qquad \text{I}$$

$$C = 0\cdot9061 - 0\cdot02661\, l + 0\cdot00241\, l^2 \quad . \quad . \quad . \quad . \qquad \text{II}$$

$$MI = 0\cdot8342 - 0\cdot04834\, l + 0\cdot004269\, l^2 \quad . \quad . \quad . \quad . \qquad \text{III}$$

where M is the percentage of mature fibres
C is maturity coefficient,
MI is maturity index, and
l is length-grade in units of one-eighth of an inch.

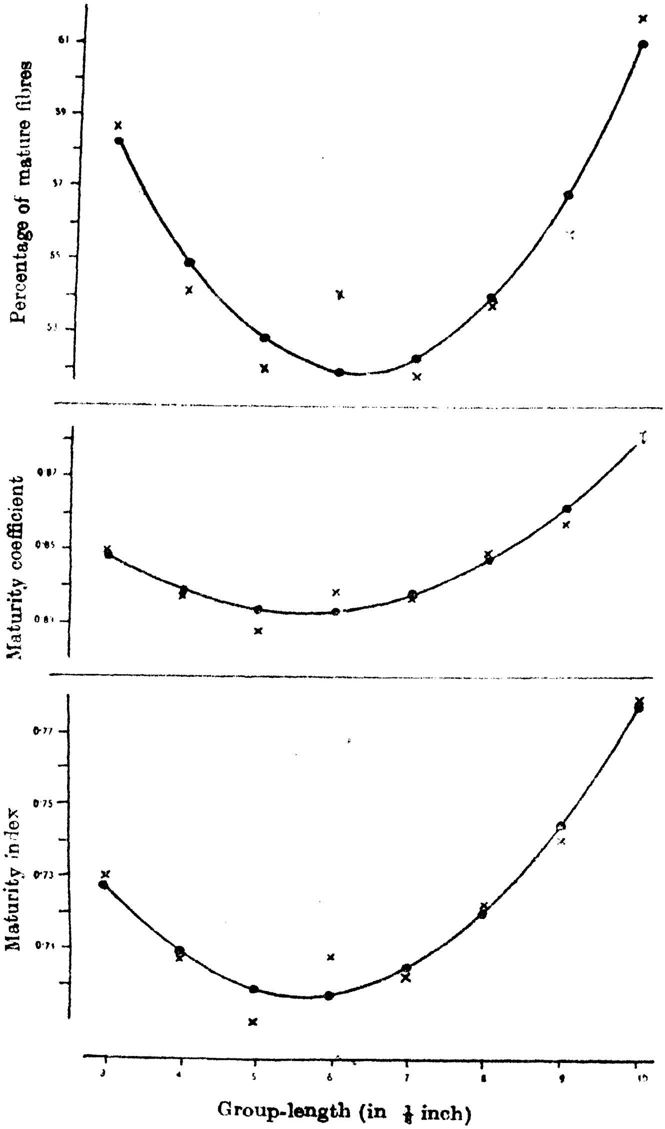
TABLE IV

Observed and calculated values of maturity terms

l	M		C		MI	
	Observed	Calculated	Observed	Calculated	Observed	Calculated
1	2	3	4	5	6	7
3 . .	58·66	58·27	0·8492	0·8480	0·7300	0·7276
4 . .	54·15	54·93	0·8379	0·8382	0·7075	0·7091
5 . .	52·06	52·83	0·8278	0·8333	0·6906	0·6992
6 . .	54·14	51·97	0·8386	0·8332	0·7084	0·6978
7 . .	51·88	52·35	0·8372	0·8379	0·7027	0·7050
8 . .	53·88	53·97	0·8497	0·8475	0·7227	0·7207
9 . .	55·74	56·82	0·8580	0·8618	0·7407	0·7449
10 . .	61·66	60·92	0·8823	0·8810	0·7792	0·7777

The regression coefficients were all statistically significant to one per cent level, thus giving further proof of the reality of the variation of fibre-maturity with fibre-length. In a further analysis of variance (Tables III *a* and *b*) the sum of squares due to length-grades with seven degrees of freedom was split up into two components, the first due to the fitting up of the parabolic regression equation with two degrees of freedom and the second due to deviations from the regression equation with five degrees of freedom. The mean square due to deviations from the regression equation was non-significant, showing that the regression equation of the second degree fitted the observed data very well and completely explained the variation in fibre-maturity with fibre-length.

In columns 2, 3 and 4, 5 of Table IV are given the observed values of the two maturity terms alongside the values obtained from equations I and II respectively for comparison. These values are plotted in the form of curves in Figs. 1 and 2, where each curve shows the value obtained from the equation, while the crosses indicate the values obtained experimentally. The agreement between the observed and the calculated values will be seen to be very close.



FIGS. 1, 2 and 3

As was observed early in this paper, Gulati and Ahmad [1935] find that in a number of Indian cottons with a fairly wide range of fibre properties, the correlation coefficient between fibre-maturity and H. S. W. C. is non-significant. Further study indicated that the correlation between spinning value and percentage of mature fibres was negative for short-staple cottons and positive for medium and long-staple cottons. From a study of Figs. 1 and 2, it will be found that as group-length increases from $\frac{3}{8}$ to $\frac{6}{8}$ of an inch, both the percentage of mature fibres and the maturity coefficient decrease continuously. For this part of the curve, the correlation between each of the maturity terms and group-length is negative. The nadir of the curve is reached when the group-length is $\frac{6}{8}$ of an inch. Thereafter, a further increase in group-length is accompanied by a corresponding increase in the maturity terms, so that for this part of the curve the correlation between the two variables is positive.

The total correlation coefficient between fibre-length and H. S. W. C. is as high as +0·87 [Turner and Venkataraman, 1933]. It is, therefore, natural to expect that the relation between fibre-maturity and group-length shall be similar to that between fibre-maturity and H. S. W. C. Hence the above conclusion confirms that arrived at by Gulati and Ahmad from quite different considerations altogether.

While this paper was under preparation, an article by Hawkins [1938] appeared on a study very similar to the one under report. Thirty-one samples of Acala seed-cotton were each analysed into different length-grades with a Pressley [1933] sorter. The pairs of length-grades 4/8 and 5/8, 6/8 and 7/8, and 8/8 and 9/8 inch were each bulked and the four groups thus obtained, together with the 10/8 inch length-grade, were tested for maturity by the Shirley Institute method (which is essentially the same as that used in this study). The data obtained in each group for fibre-maturity were converted into a single factor, called the 'maturity index', by the formula:

$$(MI) = \frac{(10m + 5t + i)}{10N}$$

where (MI) is the maturity index;

m is the number of mature fibres;

t is the number of intermediate fibres;

i is the number of immature fibres; and

N is the total number $(m + t + i)$ of fibres in the sample.

(In Hawkins' paper, the denominator on the right-hand side of the formula is given incorrectly as N; it ought to be $10N$ in order that the values for MI may all be less than unity.) Statistical analysis showed that the differences in maturity between the short, intermediate and long length classes were highly significant and that there was a significant second-degree curve relationship between maturity and fibre-length. He concluded that the longest and the shortest fibres in a given lot of cotton were less mature than the fibres of intermediate lengths and that the cotton breeders, who select progenies with greater proportions of the longer intermediate fibres, select towards improvement in fibre-maturity. The curve which he obtained was concave towards the length-axis, which meant that the maturity increased from a low value to a maximum and then decreased to a point lower than the initial value as the length-grade increased from low to intermediate and from intermediate to high values.

To compare the results obtained for the eight P-A cottons with those of Hawkins, maturity-indices were calculated from the values given in Appendix II using the same formula as was given by Hawkins and were compiled as in Table I (*c*). The analysis of variance, given in Table II (*c*), led to the same conclusion as in the case of the other two maturity terms that the maturity index also showed an intrinsic variation with the length-grade. A second-degree curve was fitted and the regression equation obtained was :—

$$(MI) = 0\cdot8342 - 0\cdot04834\, l + 0\cdot004269\, l^2 \quad . \quad . \quad . \quad . \quad . \quad . \qquad \text{(III)}$$

with standard errors of the regression coefficients :

$$\left.\begin{array}{r} -0\cdot04834 \pm 0\cdot00679 \\ \text{and } +0\cdot004269 \pm 0\cdot000516 \end{array}\right\} \text{equation III}$$

The regression coefficients were all highly significant and the further analysis of variance, in Table III (*c*), showed that the regression equation of the second-degree completely explained the variations in maturity-index with length-grade. The observed values of maturity-index as well as those calculated from equation III are given in columns 6, 7 of Table IV. The curve in this case (Fig. 3) was convex towards the length-axis. The maturity-index decreased from a high value to a minimum and then increased to a point higher than the initial value as the length-grade increased from 3/8 to 6/8 and from 6/8 to 10/8 inch. A closer study of the values given by Hawkins revealed the fact that all his samples were of a very low percentage of mature fibres, that is, they were predominantly immature, compared with the samples used herein. Hence, perhaps the curve given by Hawkins had the curvature in a direction opposite to that obtained in the present investigation.

V. CONCLUSIONS

From the study of the eight P-A cottons discussed in this paper, it can be concluded that, as the group-length increases from 3/8 to 6/8 inch, the mean percentage of mature fibres (and also maturity coefficient and maturity index) decreases, but further increase of group-length is accompanied by an increase of the mean maturity terms. This confirms the statement made by Gulati and Ahmad, that the correlation coefficient between spinning value and percentage of mature fibres is negative for short-staple cottons and positive for medium- and long-staple cottons.

VI. SUMMARY

Eleven varieties of cotton grown in the Punjab were analysed into different length-grades with a Balls Sledge sorter and the fibres in each length-grade were tested for maturity. Statistical analysis was applied to eight varieties only, and all of them were improved P-A cottons with medium staple-lengths. Of the other three, one was the *desi* cotton, 39 Mollisoni, another was a new cross, Jubilee, and the third was P-A 4F, and all of these were much shorter in staple. The analysis showed that for the eight varieties, the three maturity terms, percentage of mature fibres (*M*), maturity coefficient (*C*), and maturity index (*MI*), varied with group-length (*l*) in a manner which was described by the three regression equations :—

$$M = 75\cdot734 - 7\cdot681\, l + 0\cdot62\,0 l^2$$

$$C = 0{\cdot}9061 - 0{\cdot}02661\,l + 0{\cdot}002410\,l^2$$

and $$MI = 0{\cdot}8342 - 0{\cdot}04834\,l + 0{\cdot}004269\,l^2$$

where l is in units of one-eighth of an inch.

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REFERENCES

Ahmad, N. (1932). *Ind. Cent. Cott. Comm. Tech. Lab. Tech. Bull. Series A, No.* **21**, **10**

Ahmad, N. and Gulati, A. N. (1936). *J. Text. Inst.* T109

Gulati, A. N. and Ahmad, N. (1935). *Ind. Cent. Cott. Comm. Tech. Lab. Tech. Bull. Series B, No.* **20**

Hawkins, R. S. (1938). *J. Agric. Res.* **57**, 583

Iyengar, R. L. N. (1939). *Ind. J. Agric. Sci.* **9**, 305-27

Iyengar, R. L. N. and Turner, A. J. (1930). *Ind. Cent. Cott. Comm. Tech Lab. Tech. Bull. Series B, No.* **7**

Koshal, R. S. (1934). *J. Agric. Sci.* **24**, 105-35

Nanjundayya, C. and Ahmad, N. (1938). *Ind. Cent. Cott. Comm. Tech. Lab. Tech. Bull. Series B, No.* **24**

Peirce, F. T. and Lord, E. (1934). *E. C. G. C. Second Conf. on Cotton Growing Problems, Rep. and summary of proc.*, pp. 223-52

Pressley, E. H. (1933). *J. Amer. Soc. Agron.* **25**, 89-98

Turner, A. J. (1929). *Ind. Cent. Cott. Comm. Tech. Lab. Tech. Bull. Series B, No.* **4**

Turner, A. J. and Venkataraman, V. (1933). *Ind. Cent. Cott. Comm. Tech. Lab. Tech. Bull. Series B, No.* **17**

APPENDIX I

Fibre particulars of bulk samples

1. Fibre-length distribution (Balls sorter)

Mean group-length in eighths of an inch	Percentage										
	Punjab-*desi*		Punjab-American								
	39 Molli-soni	Jubilee	289F	289F/ 43	289F/ K 25	4F	L S S	47F	58F	100F	104F
2	1·0	1·1	1·1	2·2	2·0	1·6	1·6	1·5	1·4	1·3	1·7
3	2·6	2·9	2·3	2·8	2·5	3·3	2·7	2·1	2·4	2·2	2·3
4	5·7	5·7	3·4	4·4	4·9	5·5	3·7	3·6	3·4	3·5	3·5
5	15·9	12·0	5·1	8·2	8·3	14·7	8·1	7·2	5·7	6·1	5·8
6	44·6	34·3	9·1	15·4	13·2	39·3	14·5	13·4	9·5	10·8	11·5
7	25·6	31·4	15·3	22·0	22·0	27·4	26·9	25·8	18·9	21·6	19·5
8	4·6	9·7	29·0	28·0	29·9	6·0	29·6	30·9	32·7	36·4	31·0
9	..	2·9	25·6	13·7	14·2	2·2	10·2	12·9	18·9	14·7	18·4
10	..	..	6·8	2·8	2·5	..	2·7	2·6	5·7	3·0	4·6
11	..	..	2·3	0·5	0·5	..	..	..	1·4	0·4	1·7
2. Fibre-length (cm.)—											
(*a*) Mean . .	1·89	1·97	2·43	2·22	2·23	1·92	2·21	2·25	2·36	2·31	2·35

(*b*) Mode	1·98	2·07	2·73	2·49	2·55	2·01	2·45	2·50	2·65	2·63	2·64
3. Fibre-length irregularity (per cent)	12·2	14·4	20·6	23·5	24·6	14·0	20·3	19·8	17·5	21·0	21·7
4. Fibre-weight per unit length (millionths of a gram per cm.)	3·00	2·55	1·49	1·32	1·51	1·90	1·65	1·63	1·78	1·64	1·49
5. Fibre-maturity test results (per cent)—											
(*a*) Mature	83·3	77·3	70·8	45·0	43·6	47·7	56·8	56·2	68·5	60·2	54·5
(*b*) Half-mature	16·3	21·0	25·8	38·7	37·2	39·2	33·5	34·5	27·0	30·9	29·5
(*c*) Immature	0·4	1·7	3·4	16·3	19·2	13·1	9·7	9·3	4·5	8·9	16·0

APPENDIX II

Number and percentages of fibres mature, half-mature and immature, maturity coefficient and maturity index in each group-length

Group-length	Number of fibres				Percentage of fibres			Maturity coefficient	Maturity index
	Total	Mature	Half mature	Immature	Mature	Half mature	Immature		
					39 Mollisoni				
2	249	187	49	13	75·1	19·7	5·2	0·9221	0·8546
3	556	490	50	16	88·1	9·0	2·9	0·9617	0·9291
4	501	436	55	10	87·0	11·0	2·0	0·9616	0·9271
5	683	600	78	5	87·9	11·4	0·7	0·9674	0·9363
6	583	500	82	1	85·8	14·0	0·2	0·9639	0·9281
7	566	500	57	9	88·3	10·1	1·6	0·9661	0·9353
8	522	440	79	3	84·3	15·1	0·6	0·9590	0·9192
					Jubilee				
2	337	240	62	35	71·2	18·4	10·4	0·8969	0·8145
3	511	358	124	29	70·0	24·3	5·7	0·9081	0·8276
4	530	375	109	46	71·7	20·6	8·7	0·9008	0·8191
5	526	392	100	34	74·6	19·0	6·4	0·9169	0·8468
6	510	402	88	20	78·9	17·2	3·9	0·9353	0·8784
7	534	441	74	19	82·7	13·8	3·5	0·9458	0·8987
8	502	418	75	9	83·3	14·9	1·8	0·9528	0·9092
9	504	427	71	6	84·8	14·0	1·2	0·9582	0·9188
					P-A 289F				
2	502	386	91	25	76·9	18·1	5·0	0·9273	0·8645
3	555	419	86	50	75·5	15·5	9·0	0·9117	0·8414
4	532	399	108	25	75·0	20·3	4·7	0·9234	0·8562
5	512	322	146	44	62·9	28·5	8·6	0·8814	0·7801
6	544	365	136	43	67·1	25·0	7·9	0·8940	0·8039
7	548	391	113	44	71·4	20·6	8·0	0·9043	0·8246
8	540	376	137	27	69·6	25·4	5·0	0·9091	0·8281
9	573	386	157	30	67·4	27·4	5·2	0·9027	0·8159
10	523	370	141	12	70·7	27·0	2·3	0·9200	0·8445
11	511	362	131	18	70·9	25·6	3·5	0·9165	0·8401
					P-A 289F/43				
2	298	135	93	70	45·3	31·2	23·5	0·7928	0·6326
3	545	271	178	96	49·7	32·7	17·6	0·8215	0·6782
4	544	210	197	137	38·6	36·2	25·2	0·7709	0·5923
5	547	233	192	122	42·6	35·1	22·3	0·7896	0·6238
6	517	202	185	130	39·1	35·8	25·1	0·7722	0·5948
7	547	195	232	120	35·7	42·4	21·9	0·7733	0·5905
8	540	235	209	96	43·5	38·7	17·8	0·8055	0·6465
9	514	243	190	81	47·3	37·0	15·7	0·8209	0·6733
10	540	259	233	48	48·0	43·1	8·9	0·8432	0·7043
11	259	136	91	32	52·5	35·1	12·4	0·8442	0·7131

APPENDIX II—*contd.*

Group-length	Number of fibres				Percentage of fibres			Maturity coefficient	Maturity index
	Total	Mature	Half mature	Immature	Mature	Half mature	Immature		
					P-A 289F/K 25				
2 . . .	455	215	145	95	47·2	31·9	20·9	0·8055	0·6527
3 . . .	549	215	162	172	39·2	29·5	31·3	0·7539	0·5705
4 . . .	548	217	213	118	39·6	38·9	21·5	0·7844	0·6119
5 . . .	515	206	144	165	40·0	28·0	32·0	0·7539	0·5718
6 . . .	564	201	218	145	35·6	38·7	25·7	0·7620	0·5753
7 . . .	505	157	225	123	31·1	44·6	24·3	0·7546	0·5580
8 . . .	550	197	255	98	35·8	46·4	17·8	0·7861	0·6078
9 . . .	536	256	205	75	47·8	38·2	14·0	0·8088	0·6828
10 . . .	562	257	226	79	45·7	40·2	14·1	0·8221	0·6724
11 . . .	536	223	236	77	41·6	44·0	14·4	0·8109	0·6506
					P-A 4F				
2 . . .	374	215	101	58	57·5	27·0	15·5	0·8472	0·7254
3 . . .	568	312	155	101	54·9	27·3	17·8	0·8340	0·7035
4 . . .	510	232	184	94	45·5	36·1	18·4	0·8084	0·6537
5 . . .	533	267	162	104	50·1	30·4	19·5	0·8167	0·6724
6 . . .	555	205	214	136	36·9	38·6	24·5	0·7688	0·5867
7 . . .	534	249	195	90	46·6	36·5	16·9	0·8160	0·6657
8 . . .	547	259	212	76	47·3	38·8	13·9	0·8267	0·6812
9 . . .	519	217	233	69	41·8	44·9	13·3	0·8146	0·6559
					LSS				
2 . . .	385	241	92	52	62·6	23·9	13·5	0·8660	0·7590
3 . . .	501	313	122	66	62·5	24·3	13·2	0·8667	0·7597
4 . . .	548	338	136	74	61·7	24·8	13·5	0·8637	0·7544
5 . . .	530	307	140	83	57·9	26·4	15·7	0·8478	0·7270
6 . . .	534	289	171	74	54·1	32·0	13·9	0·8437	0·7152
7 . . .	530	272	188	70	51·3	35·5	13·2	0·8387	0·7038
8 . . .	554	296	181	77	53·4	32·7	13·9	0·8419	0·7116
9 . . .	506	265	203	38	52·4	40·1	7·5	0·8584	0·7377
10 . . .	523	362	124	37	69·2	23·7	7·1	0·9018	0·8178
					P-A 47F				
2 . . .	459	264	127	68	57·5	27·7	14·8	0·8493	0·7283
3 . . .	541	327	145	69	60·4	26·8	12·8	0·8628	0·7512
4 . . .	588	321	194	73	54·6	33·0	12·4	0·8492	0·7233
5 . . .	524	266	189	69	50·7	36·1	13·2	0·8374	0·7011
6 . . .	524	317	136	71	60·5	25·9	13·6	0·8606	0·7483
7 . . .	574	323	185	66	56·3	32·2	11·5	0·8562	0·7354
8 . . .	559	269	225	65	48·1	40·3	11·6	0·8354	0·6941
9 . . .	544	259	215	70	47·6	39·5	12·9	0·8304	0·6866
10 . . .	554	328	186	40	59·2	33·6	7·2	0·8763	0·7671

APPENDIX II—*contd.*

Group-length	Number of fibres				Percentage of fibres			Maturity coefficient	Maturity index
	Total	Mature	Half mature	Immature	Mature	Half mature	Immature		
					P-A 58F				
2 . . .	418	289	94	35	69·1	22·5	8·4	0·8977	0·8122
3 . . .	530	373	105	52	70·4	19·8	9·8	0·8965	0·8126
4 . . .	500	325	123	52	65·0	24·6	10·4	0·8813	0·7834
5 . . .	528	329	163	36	62·3	30·9	6·8	0·8853	0·7843
6 . . .	556	376	149	31	67·6	26·8	5·6	0·9023	0·8158
7 . . .	526	349	158	19	66·4	30·0	3·6	0·9050	0·8173
8 . . .	548	402	125	21	73·4	22·8	3·8	0·9219	0·8515
9 . . .	522	407	97	18	78·0	18·6	3·4	0·9346	0·8760
10 . . .	505	400	92	13	**79·2**	18·2	2·6	0·9403	0·8857
11 . . .	501	374	110	17	74·6	22·0	**3·4**	0·9264	0·8597
					P-A 100F				
2 . . .	425	285	83	57	67·1	19·5	13·4	0·8774	0·7816
3 . . .	558	343	145	70	61·5	26·0	12·5	0·8660	0·7572
4 . . .	539	311	164	64	57·7	30·4	11·9	0·8586	0·7410
5 . . .	544	264	177	103	48·5	32·6	18·9	0·8145	0·6669
6 . . .	546	321	153	72	58·8	28·0	13·2	0·8574	0·7412
7 . . .	582	333	186	63	57·2	32·0	10·8	0·8606	0·7428
8 . . .	511	278	192	41	54·4	37·6	8·0	0·8619	0·7399
9 . . .	564	325	202	37	57·6	35·8	6·6	0·8744	0·7619
10 . . .	541	346	165	30	64·0	30·5	5·5	0·8932	0·7976
11 . . .	433	272	137	24	62·8	31·6	5·6	0·8904	0·791
					P-A 104F				
2 . . .	389	182	114	93	46·8	29·3	23·9	0·7952	0·6383
3 . . .	548	259	158	131	47·3	28·8	23·9	0·7964	0·6407
4 . . .	532	218	171	143	41·0	32·1	26·9	0·7718	0·5974
5 . . .	508	262	134	112	51·6	26·4	22·0	0·8128	0·6697
6 . . .	503	253	151	99	50·3	30·0	19·7	0·8167	0·6728
7 . . .	522	238	181	103	45·6	34·7	19·7	0·8048	0·6490
8 . . .	559	295	178	86	52·8	31·8	15·4	0·8358	0·7023
9 . . .	504	241	203	60	47·8	40·3	11·9	0·8338	0·6915
10 . . .	544	345	165	34	**63·4**	30·3	6·3	0·8898	0·7921
11 . . .	344	195	116	33	56·7	33·7	**9·6**	0·8629	0·7451

STUDIES IN THE PHYSIOLOGY OF RICE

I. EFFECT OF PHOSPHORUS DEFICIENCY ON GROWTH AND NITROGEN METABOLISM IN RICE LEAVES

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(With Plate XII)

THE cultivation of rice in unmanured fields and in silts deposited by various rivers is in practice throughout Bengal and other rice-growing provinces in India. The necessary elements are presumed to be present in the soil. In the case of nitrogen, De [1939] has demonstrated its fixation from the atmosphere by blue-green algae in rice fields, but in the case of phosphorus and of other elements it is not known how much is needed by the plant and how the losses occasioned by the cultivation of rice in successive years affect the metabolic activities on which the yield depends. Large tracts of soil in Bengal are known to be lacking in phosphorus and the concentration of the element fluctuates considerably in silt deposits. The crop yield varies greatly in different localities. How far the variation in yield is due to the deficiency of any particular nutrient needs to be investigated.

Owing to the importance of the problem the present investigation was undertaken to study the effect of phosphorus deficiency on growth and nitrogen metabolism of rice. The problem is a large one and requires the cultivation of rice under a wide manurial scheme. The experimental approach to the problem is twofold : (1) the plants are grown in sand culture using three levels of phosphorus and the growth data and the nitrogen metabolism of successive leaves are studied, (2) plants are subjected to an initial period of phosphorus starvation followed by the addition of the deficient element ; the subsequent changes induced in the growth rate are investigated.

Various workers have presented data having a bearing on the aspects of phosphorus nutrition considered here. An intimate relation between protein synthesis and phosphorus supply has been established by Eckerson [1931], MacGillivray [1927], Kraybill and Smith [1924] and Richards and Templeman [1936]. Richards and Templeman have made a detailed investigation on the effect of phosphorus starvation in barley, and have shown that main visual characteristics are dark green leaves and reduced number of tillers. Under phosphorus starvation nitrogen metabolism is seriously impaired, the synthesis of protein is inhibited and there results an accumulation of amide. The feeding of detached leaves from phosphorus-starved barley with a suitable dose of phosphorus has been found by Sircar [1936] to assist protein synthesis.

EXPERIMENTAL PROCEDURE

A pure strain of rice, variety Bhasamanik, was used in this investigation. The plants were grown in sand culture in the open air at the experimental garden of the Botany Department of Calcutta University. Seeds* were selected for uniformity of size and colour by eye. After sterilization with 0·2 per cent formalin, nine seeds were sown in each pot in sand culture. Glazed pots 10 in. by 10 in. were used holding 30 lb. of sand, which was thoroughly washed with tap water. Each pot was provided with a hole for the drainage of surplus water. A bent glass tube fitted into the hole served also to indicate the level of water inside the pot. Water and nutrients were supplied through a small earthenware pot, placed at the centre of the culture pot.

The amounts of different nutrients required for growing rice in sand culture are unknown and an investigation is in progress in the Botanical Laboratory, Calcutta University, to determine the optimum requirements of potassium, nitrogen and phosphorus under these conditions. Pending the results of this experiment the nutrient employed is based on that of Gregory and Richards [1929] for the cultivation of barley. The same solution has yielded good results with wheat in this laboratory [Sircar, 1939]. Dastur and Malkani [1933] have suggested that both ammonium and nitrate ions are essential for rice. They found that the cation is preferentially absorbed in the early stage of development and the anion later at the time of flowering. In view of this in the present experiment ammonium nitrate replaced the sodium nitrate of Gregory's solution.

The following weights of salts per pot were used as the standard nutrient:—

Ammonium nitrate (NH_4NO_3)	3·00 gm.
Sodium hydrogen phosphate (Na_2HPO_4. 12 H_2O) . .	2·52 „
Magnesium sulphate ($MgSO_4$. $7H_2O$)	1·27 „
Potassium sulphate (K_2SO_4)	1·85 „
Calcium chloride ($CaCl_2$. $6H_2O$)	0·37 „

Traces of ferric chloride and manganese sulphate.—For phosphorus deficiency two levels of phosphorus were used, namely 1/3rd and 1/27th of the standard amount, each pot thus receiving 0·84 gm. and 0·093 gm. of phosphate respectively. The three series are designated full manure (1·00 P), 0·33 phosphorus (0·33 P) and 0·037 phosphorus (0·037 P). In treatments full manure and 0·33 P, 20 pots each and in 0·037 P, 26 pots were used.

In the deficient series the reduction in sodium necessitated by the reduction in phosphorus was corrected by the addition of the requisite amount of sodium sulphate. After 12 weeks the deficiency in six pots of 0·037 P series was made good by the addition of 2·427 gm. of sodium hydrogen phosphate per pot.

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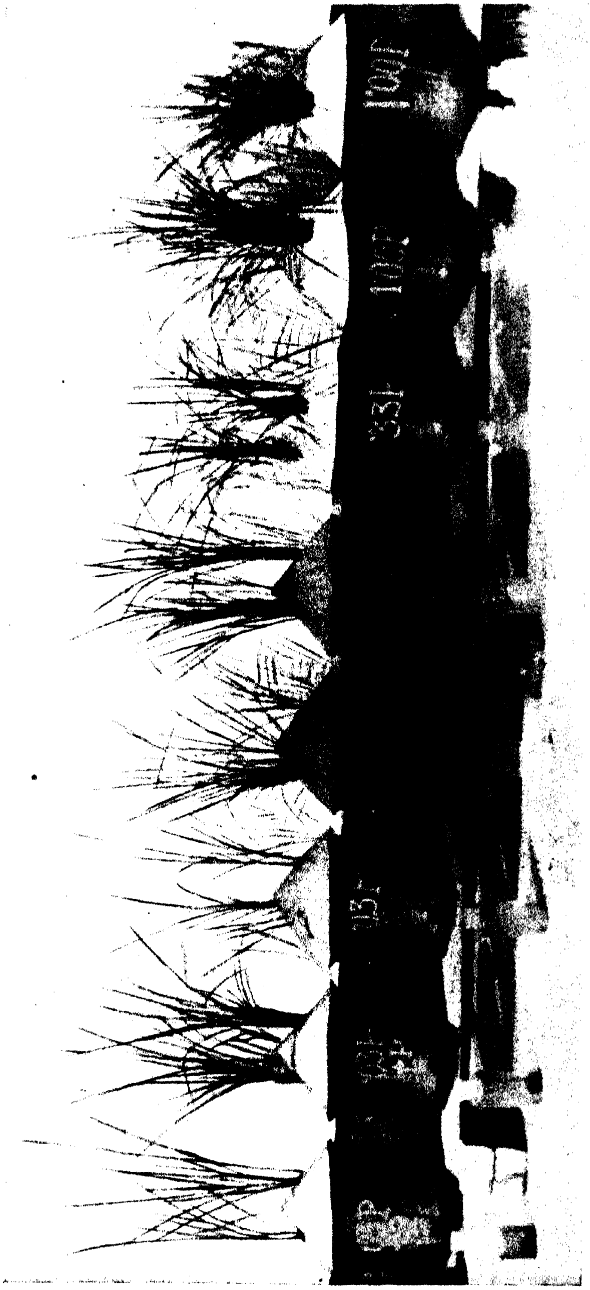
* Seeds of variety Bhasamanik were obtained from the Chinsurah Rice Research Station of the Department of Agriculture, Bengal, for which thanks are due to the authorities.



Growth of rice seedlings with different nutrients

Germination of the seeds was complete in the course of a week. When the seedlings were a little developed and the first leaf unfolded, the plants were thinned to three per pot uniform in size and spacing. The nutrients were applied to the young plants in dilute solutions in three weekly doses. In each dose salts were dissolved separately in 25 c.c. distilled water and then the *p*H of the solution was adjusted to 6·5. The first dose was applied immediately after the plants were thinned down and the last dose on 14 August 1938 after the emergence of the sixth leaf.

During the first month tap water was used for watering : the rains then set in. The excess of rain water was drained through the hole at the bottom of the pot and was collected in a bottle, whence it was subsequently returned to the pot, thus avoiding any loss of nutrients. Owing to the heavy shower of rains in the monsoon months, the probability of overflow of water from the pot with a consequent loss of nutrients was high. This was prevented by placing a tin cover over the pot. The tin cover is made in three sections and is easily detachable when necessary. It is provided with three holes to allow the plants to grow freely (Plate XII). With this arrangement it is possible to prevent any overflow during heavy showers.

ANALYTICAL METHOD

In each pot there were three plants, so besides growth measurement there were sufficient plants for leaf sampling. Eight to ten leaves, just at the time of their complete maturity, were collected at random from the main shoot of different pots before 8 A.M. and were taken to the laboratory in glass tubes lined with moistened filter paper. With the treatments adopted, the times taken to reach complete maturity by corresponding leaves differed by only a few days.

The leaves were immediately bisected longitudinally, cut into small bits and weighed. One half was dried at 70°C. for 24 hours and finally at 100°C. for 30 minutes. The dried leaves were powdered in a mortar and from the dry powder total nitrogen was estimated using the micro-Kjeldahl apparatus of Parnas and Wagner as described by Pregl [1930]. Reduction of nitrate was carried out by the reduced iron method of Pucher, Leavenworth and Vickery [1930]. Meanwhile the other half was thoroughly ground in a mortar to a paste with phenol-water. The extract was filtered through paper pulp and made up to 50 c. c. with several washings of distilled water by using a filter pump. Frothing was prevented by adding a few drops of capryl alcohol. It was found that after adequate grinding with strict economy in the use of washing water about 97-98 per cent of the soluble nitrogen could be extracted in this volume of water. Protein was removed from the extract by adding 50 per cent solution of trichloracetic acid in the proportion of 1 c. c. acid to 19 c. c. extract and filtering. From the filtrate total crystalloid nitrogen was estimated as before by the micro-Kjeldahl method after reduction of nitrates. Protein nitrogen was calculated by the difference between the total nitrogen and crystalloid nitrogen content.

Total amino nitrogen was determined by an adaptation of Brown's modification [1923] of Sorensen's formol-titration method. Amide nitrogen was estimated by hydrolysing the protein-free extract with sulphuric acid and estimating the ammonia produced by Wolff's method [1928].

EXPERIMENTAL RESULTS

Growth analysis

Weekly tiller count and height measurements of the plants were taken from the seventh week after sowing. The measurement adopted was the length of the main shoot from its base to the tip of the highest leaf. Since 20 plants would suffice for statistical analysis, one particular plant from each pot was measured in successive weeks. The mean values of height and tiller number of 20 plants per week are given in Tables I and II respectively. During the first five weeks all the plants were indistinguishable, differences first becoming noticeable during the sixth week. From the seventh week onward, a very marked difference in the general appearance of the plants grown under different levels of phosphorus was noticed.

TABLE I

Height in cm.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full manure (1·00 P)	44·32	50·92	58·10	62·25	67·99	70·37	74·07	79·51
0·33 P . .	45·37	50·03	54·85	61·42	65·42	68·64	71·66	77·38
0·037 P . .	39·85	46·10	49·19	53·28	59·40	62·04	64·89	71·05
0·037 P + 0·963 P	..	..	..	..	..	..	73·53	82·45

TABLE II

Tiller No.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full manure (1·00 P)	2·20	2·65	3·90	4·75	5·50	6·05	7·25	7·85
0·33 P . .	2·05	2·35	2·85	3·05	3·20	3·25	3·75	4·00
0·037 P . .	1·10	1·55	2·10	2·25	2·65	2·65	2·75	2·85
0·037 P + 0·963 P	..	..	..	..	..	..	3·16	4·00

The plants from the full-manure series were the most vigorous in vegetative growth and became bushy (Plate XII), but none of them produced ears. In deficient series on the other hand with fewer tillers and reduced vegetative growth the plants produced fertile ears. The failure of the high phosphorus plants to flower in conjunction with their excessive vegetative growth is possibly due to a very high uptake of nitrogen leading to low carbon-nitrogen ratio.

Starvation symptoms included dull green to yellowish green leaves, and this colour difference is more pronounced in 0·037 P series than 0·33 P series. The leaves were reduced in size and after full emergence their distal ends were dried up. In the six pots of 0·037 P series, to which phosphorus was added during the 12th week, the rate of growth increased and symptoms of starvation disappeared. With the renewal of growth, the height of the plant and the tiller number increased considerably (Plate XII).

In the 0·037P series the size of the ear was very much reduced, but the late addition of phosphorus to the phosphorus-starved plants greatly improved the grains.

STATISTICAL ANALYSIS OF GROWTH DATA

In order to judge the significance of treatment the data were subjected to statistical examination by the technique of the analysis of variance. The ratios of the variance between treatments (2 degrees of freedom) to that 'within' treatments (57 degrees of freedom) for the later sampling times are given in Table III with their respective expected values at the 5 per cent and 1 per cent levels.

TABLE III

Analysis of variance

Weeks after sowing	Observed ratio of variance		Expected ratio of variance	
	Height	Tiller	1 per cent	5 per cent
VII	7·03	20·20	4·98	3·15
VIII	4·60	8·54	4·98	3·15
IX	10·55	12·96	4·98	3·15
X	11·03	20·60	4·98	3·15
XI	6·04	31·10	4·98	3·15
XII	19·30	36·70	4·98	3·15
XIII	5·01	56·40	4·98	3·15
XV	5·51	88·70	4·98	3·15

All the observed ratios are significant at 1 per cent level except that for height in the eighth week and this nearly reaches the same level. The mean differences in the case of tiller number (Table V) increase regularly with age, signifying that the effect of treatments becomes more and more pronounced with age.

The superiority of full manure to 0·33 P and 0·037 P and that of 0·33 P to 0·037 P as judged from their effect on height and tiller number are shown by the difference of the means given in Tables IV and V respectively.

Significances at 5 per cent and 1 per cent levels of probability have been marked with (*) and (**) respectively.

TABLE IV

Height in cm.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full manure—0·33 P	—1·05	+0·89	+3·25	+0·83	+2·57	+1·73	+2·41	+2·13
Full manure —0·037 P	** +4·47	** +4·83	** +8·91	** +8·97	** +8·59	** +8·33	** +9·18	** +8·46
0·33 P —0·037 P	** +5·52	* +3·93	** +5·66	** +8·14	** +6·02	** +6·60	* +6·77	** +6·33

TABLE V

Tiller No.

(Weeks after sowing)

Treatment	VII	VIII	IX	X	XI	XII	XIII	XV
Full Manure —0·33 P	+0·15	+0·30	** +1·05	** +1·70	** +2·30	** +2·80	** +3·50	** +3·85
Full Manure —0·037 P	** +1·10	** +1·10	** +1·90	** +2·50	** +2·95	** +3·40	** +4·50	** +5·00
0·33 P —0·037 P	** +0·95	** +0·80	* +0·85	* +0·80	+0·55	+0·60	* +1·00	** +1·15

The effect of the addition of 0·963 phosphorus to the 0·037 P series as measured by height and tiller number is given in Tables I and II respectively. The significance of the effect in both the groups was examined as before. The ratios of variance between treatments (one degree of freedom) and within treatments (24 degrees of freedom) are given in Table VI with the expected variance ratios at 5 per cent and 1 per cent levels.

TABLE VI

Ratios of variance

Weeks after sowing	Observed ratio of variance		Expected ratio of variance	
	Height	**Tiller**	**5 per cent**	**1 per cent**
XIII	**1·9**	**1·09**	**4·26**	**7·82**
XV	**8·2**	**13·6**	**4·26**	**7·82**

The effect of treatment is not significant at the 13th week but is highly significant at the 15th, i.e. the application of phosphorus even at this late stage of life induces tillering and increases height.

Nitrogen analysis

The results of nitrogen fractionations are presented in Table VII as percentage of dry weight.

For lack of replicate observations these results are presented without statistical evidence. Since the analytical data as reported here are obtained from a representative number of leaves of the same stage of maturity, it is worth considering the appreciable difference between treatments. In amino acid, amide and residual nitrogen there are minor fluctuations, but from the general trend of behaviour in different leaf number the effect of phosphorus concentration is noteworthy.

Total nitrogen

In all the leaves in the full-manure series total nitrogen content is high and the level falls with decreasing phosphorus concentration. After the eighth leaf the total nitrogen falls in the successive leaves and this fall with leaf number is evident at all levels of phosphorus. The eighth leaf in all the series absorbed more nitrogen. The uptake of nitrogen then is dependent on the supply of phosphorus. Higher levels of phosphorus result in increased absorption of nitrogen. This is clearly seen in the three levels of phosphorus used in the experiment. Richards [1938] found that with increasing supply of phosphorus in the early stages of growth the uptake of nitrogen is increased.

Protein nitrogen

The highest content of protein nitrogen is found in the full-manure series and the content falls progressively with decreasing concentration of phosphorus.

TABLE VII

Nitrogen fractions expressed in percentage of dry weight

Leaf No.	Treatment	Total N	Crystal-l oid N	Protein N	Total amino N	Amide N	Amino acid N	Residual N
7	F. M.*	4·287	1·286	3·001	0·0461	0·0228	0·0233	1·2170
	0·33 P	3·929	1·274	2·655	0·0567	0·0425	0·0142	1·1747
	0·037 P	3·675	0·9931	2·6819	0·0342	0·0301	0·0041	0·9288
8	F. M.	4·382	0·6336	3·7484	0·1848	0·0293	0·1545	0·4195
	0·33 P	3·965	0·6181	3·3469	0·1429	0·0598	0·0832	0·4155
	0·037 P	3·796	0·6141	3·1819	0·1848	0·1121	0·0727	0·3172
9	F. M.	4·1875	0·4494	3·7381	0·1266	0·0344	0·0923	0·3084
	0·33 P	3·6846	0·5316	3·1530	0·1557	0·0944	0·0613	0·2815
	0·037 P	3·2865	0·4173	2·8692	0·1833	0·1153	0·0680	0·1187
10	F. M.	3·5645	0·3636	3·2009	0·0867	0·0286	0·0581	0·2482
	0·33 P	3·2493	0·3383	2·9110	0·0915	0·0394	0·0521	0·2175
	0·037 P	2·9005	0·3874	2·5131	0·1003	0·0733	0·0270	0·2138

* F. M.=Full manure

These relations are found in each of the four leaves investigated. The effect of phosphorus starvation in lowering the protein content is more marked in the later leaves, the 9th and 10th leaves, showing greater variation in protein content between treatments than the 7th and 8th. The decrease in protein nitrogen with falling phosphorus supply closely simulates that of total nitrogen. It will be noted that as compared with total nitrogen, protein nitrogen content rises more steeply from leaf 7 to leaf 8 and that the subsequent decline is rather slower. As between the 7th and 8th leaves therefore there is a consistent difference, at all phosphorus levels, of the relative contents of protein and crystalloid nitrogen.

Amino acid nitrogen

In estimating the values for amino acid nitrogen the following assumption is made. It is generally believed that the plant amide exists mainly in the form of asparagine which behaves as a mono-carboxylic mono-amino acid. Since one of the COOH group of aspartic acid is neutralized by the amide group, only one is available for formol-titration. The formol-titration figures therefore included only half of the total nitrogen of asparagine. The amide figures also include half the nitrogen of the asparagine. Hence the absolute values of 'amino acid nitrogen' presented here (all amino acids less those united to an amide group) are estimated from the difference between the formol-titration figure and the amide titration figure.

The amino acid values in all treatments increase from the 7th leaf to the 8th and subsequently fall again, but a value higher than that of the 7th leaf is maintained up to the 10th. Somewhat similar relationships were found with protein nitrogen content. Increasing phosphorus starvation has resulted in a progressively reduced amino acid content, and this is found in all the leaves. The results presented here do not seem to agree with those obtained by Richards and Templeman [1936], who noticed in barley a higher amino acid content in phosphorus-starved than in full-manure leaves.

Amide nitrogen

No separate estimation of ammonia was made, hence the amide figures presented here will include in addition all the free ammonia that may be present in the leaves. As the plants were supplied with ammonium nitrate, this may be absorbed in considerable amounts, but Prianischnikoff [Onslow, 1931] has shown that free ammonia, which is toxic, is quickly converted to asparagine. From this it may be presumed that the ammonium ion if present at all is in inappreciable quantity.

Amide nitrogen from the 7th leaf increases to the 9th, but in the 10th it again falls. A large and progressive increase in amide nitrogen following the lowering of phosphorus concentration is found in the leaves analysed. Strikingly high amide contents are found in the 8th and 9th leaves of the most deficient series ; the content falls again in the 10th leaf but still remains higher than in the 7th. The results are in agreement with those of Richards and Templeman, who noticed an accumulation of amide in barley grown under phosphorus deficiency. As the plants age, the accumulation of amide under phosphorus deficiency is presumably a reflection of the retarded rate of protein synthesis.

Residual nitrogen

The residual crystalloid nitrogen is the nitrogen not estimated in any of the other groups. The figures are obtained from the difference between the total crystalloid nitrogen and the sum of total amino and amide nitrogen. Since the plants were supplied with ammonium nitrate, the residual crystalloid nitrogen will contain any nitrate remaining unmetabolized. No separate estimation of nitrate was made, but possibly the nitrate content may be roughly estimated from the residual crystalloid nitrogen content.

In the 7th leaf a high value of residual nitrogen is observed and this falls rapidly in later leaves, a very sharp fall occurring from the 7th to the 8th. If it be assumed that residual nitrogen consists largely of nitrate, then it follows that up to the 7th leaf much of the absorbed nitrate has remained unmetabolized. The contents of amide nitrogen in the 7th leaf are low, and these include also all free ammonium ion. Hence ammonia is either not absorbed in these earlier stages or else is metabolized to protein as soon as it is absorbed. But Dastur and Malkani [1933] have definitely shown that the ammonium ion is absorbed in larger quantities than is nitrate in the earlier stages. Hence it appears likely that ammonia is utilized for the synthesis of protein as soon as absorbed, while the absorbed nitrate remains largely unused and accumulates at this time. In the 8th leaf a large reduction in residual nitrogen is noticed, and this accompanies a roughly equal increase in protein nitrogen. Reduction in phosphorus concentration lowers the residual nitrogen content just as it does the total nitrogen content and that of all observed fractions with the exception of amide.

Nitrogen analysis of the ears

Since only 6 pots were used for the application of phosphorus to phosphorus-starved plants, the leaf material was insufficient for estimating the various nitrogen fractions in the successive leaves. But from the ripe ears nitrogen analyses were made and the data are presented in Table VIII.

TABLE VIII

Analysis of ears

Treatment	Total N	Crystalloid N	Protein N	Total amino N	Amide N
0·33 P	1·9313	0·1362	1·7951	0·0079	Trace
0·037 P	1·6970	0·1678	1·5292	0·0158	”
0·037 P + 0·963 P . .	1·9393	0·1496	1·7897	0·0085	”

It is evident that nitrogen content in the ears has increased after the addition of phosphorus. The increase in total nitrogen is accompanied by an increase in protein nitrogen, while only traces of amide and amino nitrogen are found; nearly all the soluble nitrogen appears as ‘residual nitrogen’. The probability of the presence of nitrate in the grains in concentrations, such as those of residual nitrogen, is very unlikely, and further research is necessary to determine the nature of the substances represented. They may consist largely of relatively short-chain compounds intermediate between amino acids and protein.

DISCUSSION

The differences in phosphorus supply have produced marked changes in the growth of rice plants, and the characteristic symptoms of phosphorus deficiency noted by Richards and Templeman [1936] in the leaves of barley are observed also in these leaves. At the highest level of phosphorus vigorous vegetative growth occurs, and as the phosphorus level is reduced a marked decrease in both tillering rate and height of the plant results. These are found to be statistically significant. At the intermediate phosphorus level the height effect, which appears to be real enough, cannot be shown to be statistically significant, since the observations in successive weeks are not independent, so that the data for each week must be considered individually instead of collectively. The effect on tillering is shown to be highly significant from the 9th week onwards and increases with time. At the lowest phosphorus level significant reductions in both height and tiller numbers are found even at the earliest observations and these become more pronounced with increasing age. It should be noted that the plants, which have suffered this severe deficiency for 12 weeks and are then supplied with phosphorus, recover immediately, beneficial effects being noticeable one week after the change in conditions. The deficiency symptoms disappear, tillering is renewed and growth in height accelerated. On the other hand, Brenchley [1929], working with barley, found phosphorus to be necessary in the early stages of growth, later application being unaccompanied by the formation of new tillers. The critical period was found to be between four and six weeks after sowing, later application of phosphorus to starved plants having no appreciable effect in increasing tiller number. The considerable difference in behaviour between barley used by Brenchley and rice used in the present experiment may possibly be explained by the difference in the normal rate of tillering of the two species. In barley Brenchley found a rapid rate of tiller formation in the first four weeks after which the rate began to slacken off. The majority of new tillers formed during the later period remained small and died prematurely. In rice the maximal rate of tillering is later and the period over which new shoots are produced is prolonged. Tiller production at any one stage of life-history is not only a function of the nutrient supply at that time, but is also a function of certain internal factors—differing in different species—responsible for the shape of the tiller productions curve under constant external conditions.

This investigation clearly shows that the absorption of nitrogen is dependent on the supply of phosphorus. As the external concentration of phosphorus is varied over a wide range, the uptake of nitrogen varies in the same sense. These results are in accord with those of Richards and Templeman for barley, but do not agree with those recorded by MacGillivray [1927] for tomatoes. He found that plants growing in sand culture under phosphorus deficiency have a higher percentage of nitrogen than those grown with ample supplies of phosphorus.

When leaves from the plants of the present experiment are compared with those from rice grown in the field,* it is found that the nitrogen content in sand culture is considerably higher than that from the soil plants. Rice plants evidently can grow normally at lower nitrogen levels than that of this experiment. In the full-manure series the excess nitrogen absorption may be the main cause of the plants making excessive vegetative growth and failing to form ears. With low phosphorus supply the uptake of nitrogen is reduced and the resulting plants produce ears ; in this respect 0·037 P plants were the best. Almost all the plants in this series formed grains, in 0·33 P series about 40 per cent produced them, while in full manure series none of the plants produced them. In 0·037 P series the total nitrogen of the 10th leaf—the last one analysed—was 2·9 per cent, a value but slightly above that obtained in the corresponding leaf of the plants grown in the field, where both good vegetative growth and good grain was noticed (2·5 per cent).

Protein nitrogen is affected by phosphorus supply in the same way as total nitrogen, the lowering of phosphorus concentration resulting in a lowering of protein nitrogen content. The decrease in protein nitrogen under phosphorus starvation is accompanied by an accumulation of amide, this accumulation being greatest under conditions of greatest deficiency. Under the same conditions the content of amino nitrogen, other than that associated with an amide group, is reduced. The accumulation of amide under phosphorus starvation has been noticed by Richards and Templeman in barley leaves, and they suggested that under these conditions protein synthesis is checked beyond the stage of the production of asparagine. Unpublished work by Sircar [1936] has shown that when phosphorus and sugar are presented in the dark to detached leaves of barley deficient in phosphorus, an increase in protein results. It was concluded that phosphorus is necessary for the synthesis of amide to protein.

In the rice leaves it has been observed that starvation symptoms disappear when deficiency is made good, and there is renewed growth in the plants as is evident from the increase in height and tiller number. This result presumably follows the revival of protein synthesis in these plants. Nitrogen analyses of the grain show increased contents of nitrogen following phosphorus feeding, and a considerable portion of the increased nitrogen is metabolized to protein (Table VIII). Evidently phosphorus is necessary for the utilization of nitrogen, but from the evidence presented here and elsewhere [Richards and Templeman 1936; Sircar, 1936] it is impossible to decide whether the main effect is direct or indirect.

SUMMARY

1. A sand-culture experiment is described in which rice var. Bhasamanik was grown at three levels of phosphorus nutrition : (1) Maximal phosphorus—the full-manure series, (2) 0·33 phosphorus at one-third the level of phosphorus used in full-manure series, and (3) 0·037 phosphorus at 1/27th.

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* An investigation on the nitrogen metabolism of the successive leaves of rice plants grown in the field is in progress, and the total nitrogen estimated in leaves No. 7, 8, 9, 10 is found to be 2·66, 2·85, 2·53, 2·51 respectively.

2. Maximum height of the plants and number of tillers were observed periodically. Progressive phosphorus deficiency leads to progressive reduction in height and tillering. The application of phosphorus to 0·037 P plants 12 weeks after sowing increases tiller number and height. The growth data are analysed statistically, and the effects of phosphorus are found to be highly significant.

The uptake of nitrogen is found to depend on phosphorus concentration, greatest uptake being associated with the highest phosphorus level. Protein synthesis is checked by shortage of phosphorus supply, and an accumulation of amides results. Free amino-acid content is reduced by phosphorus deficiency.

The effect of retarded phosphorus application is also seen in increased total nitrogen content and protein synthesis in the grains. These results demonstrate that in rice, phosphorus is not only useful in the early stages of growth but may also be utilized in the later stages of development.

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REFERENCES

Brenchley, W. E. (1929). *Ann. Bot.* **43**
Brown, J. H. (1923). *J. Bact.* **8**, 245
Dastur, R. H. and Malkani, T. J. (1933). *Ind. J. Agric. Sci.* **3**, 157
De, P. K. (1939). *Proc. Roy. Soc. B. 846*, **127**
Eckerson, S. H. (1931). *Contribution Boyce Thompson Inst.* **3**, 197
Gregory, F. G. and Richards, F. J. (1929). *Ann. Bot.* **43**, 119
Kraybill, H. R. and Smith, T. O. (1924). *Ann. Rept. Bull. New Hampshire Agric. Exp. Stat.* **212**
MacGillivray, J. H. (1927). *J. Agric. Res.* **34**, 97
Onslow, M. W. (1931). *The principles of plant biochemistry*: Cambridge. University Press
Pregl, F. (1930). *Quantitative organic micro-analysis* (English translation by E. Fyleman)
Prianischnikoff (1931). *The principles of plant biochemistry*: Cambridge University Press
Pucher, G. W.; Leavenworth, C. S. and Vickery, H. B. (1930). *Ind. & Eng. Chem. Anal. Ed. II.*, 191
Richards, F. J. (1938). *Ann. Bot. (new series)* **2**
Richards, F. J. and Templeman, W. G. (1936). *Ann. Bot.* **50**, 367
Sircar, S. M. (1936). Ph.D. thesis: University of London
————(1939). *Sci. & Culture* **5**, 3
Wolff, B. (1928). *Chem. Ind. Rev.* **6**, 1060

STUDIES ON INDIAN RED SOILS

II. FIXATION OF PHOSPHATES

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(With one text-figure)

HECK [1934] has made the following divisions of the inorganic compounds of phosphorus present in the soil :—

(*i*) Readily available fixed phosphorus—$Ca_3(PO_4)_2$
(*ii*) Moderately available fixed phosphorus—$AlPO_4$
(*iii*) Difficultly available fixed phosphorus—$FePO_4$, $Fe_2(OH)_3PO_4$, $Al_2(OH)_3PO_4$

The basis of this division is the solubility of these compounds in $0 \cdot 002N$ sulphuric acid solution buffered to *p*H 3·0 by adding 3 gm. of ammonium sulphate per litre.

Ford [1933] showed that fixation of phosphates by iron in difficultly soluble form is due to the hydrated iron oxides, such as goethite, which forms very difficultly soluble iron phosphates. The work of Gaarder [Heck, 1934] indicates that the *p*H value of the soil is an important factor in influencing the form in which phosphate is fixed up by the soil. His work shows that the amount of phosphorus going into solution from calcium phosphate at *p*H 6·5 is only about one-third of that from normal aluminium phosphate and one-fourth of that from normal iron phosphate, whereas at *p*H 5·5 the phosphorus from normal calcium phosphate has a solubility from three to five times of that in iron and aluminium forms. Besides iron and aluminium, the inorganic elements Mg, Mn and Ti may also function to some extent in the fixation of phosphorus in the soil, but their importance and exact role is either unknown or is questionable. Indeed, Bradfield, Scarseth and Steele [1935] say : 'Natural soils contain so many substances capable of fixing phosphates that it is hopeless to unravel the mechanism of fixation by the study of such complex systems '. The work of these authors shows that at *p*H values 2·0-5·0, the retention of phosphates is chiefly due to the gradual dissolution of iron and aluminium and their reprecipitation as phosphates. At *p*H values 6·0-10·0, if divalent cations are present, the phosphate will be largely fixed by divalent cations, whereas at *p*H values 4·5-7·5, the retention of phosphates by clays seems to be surface reactions in which OH ions are displaced by phosphates. Thus their work suggests that the capacity of the soil to retain phosphate ions over a wide range of reactions and concentrations is due at least to three distinctly different mechanisms.

Mention may be made here of the work of Fraps [1932] who reported that various soil minerals other than iron compounds possess the capacity of fixing phosphates. Similar results were obtained by Dean [1934].

In the present investigation Truog's [1930] method for determining the amount of available phosphates has been employed.

The present work has been divided into two sections.

Section I deals with a study on the uptake of phosphates from phospate solutions by soils after shaking the mixture of the soil and the phosphate solution for a certain time.

Section II deals with a study on the fixation of phosphates by soils from phosphate solutions when the latter are brought into equilibrium with the soil by evaporation to dryness.

Data and discussion

I. STUDY ON THE UPTAKE OF PHOSPHATES FROM PHOSPHATE SOLUTIONS BY SOILS AFTER SHAKING THE SOIL AND THE PHOSPHATE SOLUTION FOR A CERTAIN TIME

EXPERIMENTAL

Procedure for the determination of the uptake of phosphates

0·5 gm. of powdered soil passing through a 70 I. M. M. mesh were treated with 25 c.c. of a standard phosphate solution (H_3PO_4, KH_2PO_4, K_2HPO_4, K_3PO_4 as the case may be) containing 4 p.p.m. of phosphorus per c.c. (then phosphorus content with respect to soil is 200 p.p.m.) in 30 c.c. test-tubes. The soils were shaken for a certain time in a mechanical shaker, then immediately filtered through a Whatman No. 2 filter paper, the first few c.c. being discarded. A definite quantity of the filtrate was taken and P content determined according to Truog and Meyer's modification of Denige's method [1929].

Preparation of standard phosphate solutions

KH_2PO_4 solution.—0·1755 gm. of KH_2PO_4 (extra-pure, Merck) was dissolved in water and diluted to 1,000 c.c. This solution contains 40 p.p.m. of P.

K_2HPO_4 solution.—0·2245 gm. of K_2HPO_4 (extra-pure, Merck) was dissolved in water and diluted to 1,000 c.c. This solution contains 40 p.p.m. of P.

K_3PO_4 solution.—0·2754 gm. of K_3PO_4 (extra-pure, Merck) was dissolved in 1,000 c.c. of water. This solution contains 40 p.p.m. of P.

H_3PO_4 solution.—4 c.c. of phosphoric acid was diluted to 100 c.c. and 1 c.c. of this was taken and P determined according to Truog and Meyer's modification of Denige's method. It was found to contain 1,168 p.p.m. of P, 3·42 c.c. of this was diluted to 1,000 c.c., so that P content of this solution was 4 p.p.m.

Determination of pH.—*p*H was determined by the colorimetric method using the Hellige Comparator.

RESULTS

The results are presented in Tables I and II.

TABLE I

Amount of P taken up by the soil, when the soil is shaken with 200 p.p.m. of P
(KH_2PO_4 solution used)

Locality	Soil No.	Depth	p. p.m. of P taken up by the soil after shaking for different times in minutes						
			0*	30	60	90	120	180	240
Dacca Farm (Bengal)	1p	0—6 in.	73	80	130	133	136	142	142
	2p	0—2 ft. 3 in.	129	182	183	185	187	190	195
	3p	2 ft. 3 in.—4 ft.	130	181	182	183	182	183	183
Suri, Birbhum (Bengal)	5p	1 ft.—1 ft. 6 in.	73	151	158	160	168	169	170
	8p	Below 13 ft.	26	66	112	120	123	123	123
Himayatsagar (Hyderabad)	18p	0—3 in.	87	120	123	123	128	132	133
	19p	3 in.—1 ft. 6 in.	26	115	116	136	136	136	136
	20p	1 ft. 6 in.—4 ft.	30	26	65	66	66	66	66
	21p	1 ft. 6 in.—4 ft.	62	56	74	75	75	76	76
Telankheri (1) Nagpur (C. P.)	23p	0—2 ft.	56	111	144	156	162	174	174
	24p	2 ft.—2 ft. 6 in.	83	176	177	180	183	184	184
Telankheri (2) Nagpur (C. P.)	26p	13 ft.—16 ft.	60	63	63	63	63	63	63
	27p	16 ft.—21 ft.	39	68	69	69	69	69	69
Chandkhuri Farm, Raipur (C. P.)	33p	0—4 in.	80	88	91	100	106	111	112
	34p	4 in.—1 ft. 5 in.	100	142	142	150	151	151	151
	35p	1 ft. 5 in.—4 ft.	103	180	180	180	180	180	180
Puzathi, Cannanore (Madras)	48p	16 ft.—30 ft.	83	125	125	128	132	137	139
	50p	Below 30 ft.	32	115	115	121	126	126	126
	51p	Below 30 ft.	36	50	50	50	50	50	50
Nilgiri hills (1) 3,000 ft. a.s.l.	53p	0—1 ft. 8 in.	32	115	115	115	115	115	115
	54p	1 ft. 8 in.—3 ft.	37	111	139	138	140	142	154
	55p	Below 54p	68	125	126	126	126	126	126
Nilgiri hills (2), 5,000 ft. a.s.l.	56p	0—1 ft. 2 in.	25	108	129	151	174	174	174
	57p	1 ft. 2 in.—2 ft.	182	190	195	200	200	200	200
	58p	2 ft.—6 ft.	137	191	198	200	200	200	200
Nilgiri hills (3) 7,000 ft. a.s.l.	59p	0—1 ft.	40	146	158	159	163	171	195
	60p	1 ft.—3 ft.	190	197	200	200	200	200	200
	61p	3 ft.—4 ft. 6 in.	185	192	196	200	200	200	200
	62p	4 ft. 6 in.—6 ft.	190	199	200	200	200	200	200

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* This reading was actually taken after one or two minutes from the time of mixing the soil and the phosphate solution, which time was necessary for shaking the soil with solution and taking measurements.

TABLE I—*contd.*

Locality	Soil No.	Depth	p.p.m. of P taken up by the soil after shaking for different times in minutes						
			0*	30	60	90	120	180	240
Stambhalaguruva, Guntur (Madras)	67p	0—8 in. . .	30	96	99	121	126	138	146
	69p	1 ft. 2 in.—6 ft.	58	127	127	129	130	130	130
Limonite			75	79	93	115	117	118	120
Magnetite			53	66	66	66	66	66	61
Ilmenite			69	68	86	96	103	140	142
Kaolin (Indian)			20	22	22	22	22	22	21
Bauxite (Indian)			114	137	137	141	148	162	178

* This reading was actually taken after one or two minutes from the time of mixing the soil and solution, which time was necessary for shaking the soil and taking measurements.

TABLE II

Analytical data of minerals (air-dry basis)

Minerals	SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	TiO_2 (per cent	P_2O_5 (per cent)
Limonite *	2·04	5·53	76·96	1·79	0
Magnetite *	1·51	1·65	94·26	0·52	0
Ilmenite *	2·03	1·26	47·19	46·97	0
Kaolin *	39·53	11·38	2·10	0·10	0
Bauxite *	0·20	96·87	1·48	1·00	0

* These are all Indian minerals.

The mineral limonite and the titanium-bearing mineral ilmenite possess almost the same power of retaining phosphates. In many cases, the soil possess much greater power of retaining phosphates than the above minerals, whilst in some cases, the powers of soils to retain phosphates are considerably less.

It will be found from Table I that in most cases, up to about 30 minutes or one hour, the phosphate fixation proceeds at a rapid rate, the rate gradually falling off, becoming almost constant after two hours and remaining thus for the remainder of the period, during which observations were made. It will be noted that the procedure developed for comparing the fixing powers of soils involved the agitation of the soil and the phosphate solution from a few minutes to a few hours. It should not be inferred, however, that fixation is complete at the end of this period. The period required for the attainment of a true equilibrium between the soil and a soluble phosphate which has been applied to it will depend upon the nature of the soil, the magnitude of application of the phosphate and the manner in which the resulting fixation is brought about. The investigations of Davis (cited by Hance [1933]) of a high-fixing Manoa Valley soil indicate that equilibrium is not reached even after several weeks of continuous agitation of the soil-phosphate solution mixture.

The results in Table I also indicate that the adsorption of phosphates is the highest in the case of profile samples from Nilgiri hills (2) (5,000 ft. above sea level) and Nilgiri hills (3) (7,000 ft. a.s.1) and is considerably greater than in the case of the ordinary iron or titanium-bearing minerals. The most plausible explanation of this lies in the fact that there are materials present in the soil other than iron or titanium-bearing minerals, which possess considerable power of phosphate absorption. An alternative explanation can be offered that the soils of Nilgiri hills (2) and Nilgiri hills (3) are rich in colloidal iron.

Table III shows the uptake of phosphorus when phosphate is added to the soil in different forms.

The data show in general that the amount of phosphate absorbed by the soil at about equilibrium point increases with the lowering of *p*H of the phosphate solution. The high uptake of P in case of H_3PO_4 may partly be due to the coming into solution of iron and aluminium and their reprecipitation as iron and aluminium phosphates, whilst in case of K_3PO_4 the reaction is probably between divalent cations and the phosphate solution, and hence the uptake is comparatively small [Bradfield, Scarseth and Steele, 1935].

TABLE III

Amount of P taken up by the soil from different solutions

Soil description	Phosphate solution used *	p.p.m. of P taken up by the soil after shaking for different times (in minutes)						
		0**	30	60	90	120	180	240
2p, Dacca Farm (Bengal) (6 in.-2 ft. 3 in.)	H_3PO_4	14	67	178	200	200	200	200
	KH_2PO_4	120	182	183	185	187	190	195
	K_2HPO_4	21	104	155	155	158	158	158
	K_3PO_4	8	96	96	96	97	97	97
5p, Suri, Birbhum (Bengal) (1ft.-1 ft. 6 in.)	H_3PO_4	52	166	173	189	200	200	200
	KH_2PO_4	73	151	158	160	168	169	170
	K_2HPO_4	94	103	114	114	114	114	114
	K_3PO_4	25	61	70	81	82	83	83
23p, Telankheri, Nagpur (C. P.) (0 -2 in.)	H_3PO_4	138	164	186	200	200	200	200
	KH_2PO_4	56	111	144	156	162	174	174
	K_2HPO_4	33	102	102	102	121	121	135
	K_3PO_4	81	84	84	84	84	84	84
59p, Nilgiri hills (3) (0-1 ft.)	H_3PO_4	144	150	170	184	200	200	200
	KH_2PO_4	40	146	158	159	164	171	195
	K_2HPO_4	84	177	178	178	178	179	179
	K_3PO_4	64	63	67	70	72	75	75
67p, Stami halaguruva, Guntur (Madras) (0-8 in.)	H_3PO_4	130	149	185	200	200	200	200
	KH_2PO_4	30	96	99	121	126	139	146
	K_2HPO_4	2	77	79	81	93	102	103
	K_3PO_4	14	14	14	15	15	15	15

* *p*H of the phosphate solutions are :—

H_3PO_4 3·8 ; KH_2PO_4 5·6 ; K_2HPO_4 7·2 ; K_3PO_4 9·6.

**This reading was actually taken one or two minutes from the time of mixing the soil and phosphate solution which time was necessary for shaking and taking measurements.

II. FIXATION OF PHOSPHATES BY SOILS FROM PHOSPHATE SOLUTIONS WHEN THE LATTER ARE BROUGHT INTO EQUILIBRIUM WITH THE SOIL BY EVAPORATION TO DRYNESS

EXPERIMENTAL

Following the work of Scarseth, Heck [1934] has found that the most pronounced fixation of phosphate occurs in a few hours and that after a transition period, varying from two to ten days, the fixation takes the form of practically a straight line with a tendency to be somewhat asymptotic, which approaches the line of ' zero ' recovery. Heck [1934] found also that heat could in part be substituted for time and this could be accomplished by refluxing the soil in the phosphate solution at 100°C. for 45 minutes. It was also found that if the soil and the phosphate solutions were slowly boiled to dryness, the results were the same as when they are refluxed. The following procedure, which was adopted, is essentially the same as developed by Heck.

Procedure for treating the soil and phosphate solution mixture

0·5 gm. of soil, which passes through a 70 I. M. M. sieve, was placed in a 600-c.c. tall Pyrex beaker and to it 250 c.c. of KH_2PO_4 solution containing 0·000001 gm. of P per c.c. was added. This was equivalent to adding 500 p.p.m. of P to the soil. The beaker was then slowly heated to dryness in a sand-bath, till the contents were dry. It usually took six to seven hours. The dried mass was then transferred to a 500-c.c. wide-mouthed bottle and treated with 250 c.c. of 0·002 *N* sulphuric acid solution buffered to *p*H 3·0 by adding ammonium sulphate [Truog and Meyer, 1930], and shaken for half an hour in a mechanical shaker. From the extract, P was determined by following the Denige's method as modified by Truog and Meyer [1929]. Four successive extractions were made with each soil. A correction was made in each case, for the amount of soluble phosphate which might be present in the soil. The amount which came out in the sulphuric acid extract subtracted from the sum which was added and present in the soil before treatment gives the amount fixed, which makes it possible to calculate the capacity of the soil to fix P in a difficultly available form.

Hardy and Folletsmith [1931] determined the amount of aluminium and iron oxides uncombined with silica by Schmelev's Alizarin adsorption method. Their determination was based on the fact that the iron oxide in the soil can absorb alizarin sulphonate only before ignition, whilst the alumina gel can absorb alizarin sulphonate only after ignition. It was felt desirable to examine as to how far the capacities of the soil for fixation of phosphates change after ignition. Accordingly, experiments in fixation of phosphates were carried out with non-ignited as well as ignited soil materials (about 1·5 gm. of material was heated to the maximum temperature of a Bunsen burner for about 15 minutes). For the sake of comparison and for understanding the nature of substances in the soil which are responsible for phosphate fixation, measurements were carried out with some typical minerals containing iron and aluminium and titanium (ignited and non-ignited), and similar experiments were also carried out with gels of SiO_2, TiO_2, Al_2O_3, and Fe_2O_3

Preparation of gels of TiO_2, Al_2O_3, Fe_2O_3 and SiO_2

TiO_2 gel.—It was prepared by hydrolysing extra pure $TiCl_4$ in a large volume of water and was electrodialysed in a three-chambered Pauli's pattern electrodialysing apparatus, circulating cold water through anodic and cathodic chambers. The dialysis was continued till the anode was free from chloride ion.

Fe_2O_3 gel.—In a concentrated solution of pure ferric chloride, ammonia was added till the gelation was complete. The whole mass was dialysed by passing distilled water for a long time till the dialysate was free from chloride ion.

Al_2O_3 gel.—It was similarly prepared from aluminium chloride.

SiO_2 gel.—In a concentrated solution of sodium silicate, hydrochloric acid was added till the gelation was complete. The whole mass was electrodialysed in a three-chambered Pauli's pattern electrodialysing apparatus, circulating cold water through the anodic and cathodic chambers. The dialysis was continued till the anode was free from chloride ion.

After dialysis all the gels were dried at 50°C. in an electric oven.

RESULTS

Table IV shows the results on the phosphate fixation with non-ignited soils and with gels of TiO_2, SiO_2, Al_2O_3 and Fe_2O_3, whilst Table V exhibits the corresponding data with ignited materials. In these tables the 4th, 5th, 6th and 7th columns represent the amount of P coming into solution in the 1st 2nd, 3rd and 4th individual extractions, whilst the 8th column represents the total amount of P coming into solution.

The results in Table IV show that with non-ignited soils, in some cases, e.g. Nagpur and Midnapur, the amount of phosphates which is made non-available increases as the depth of the profile increases. In the case of Cannanore, on the other hand, the amount of phosphate, which is non-available, decreases with the depth. In general, however, it may be said that the amount of phosphate fixed up shows a maximum value at an intermediate depth.

Of the minerals studied, ilmenite possesses maximum power of phosphate fixation, the next in order being haematite. Of the gels studied, Fe_2O_3 and TiO_2 possess a very high power of phosphate fixation, that by Al_2O_3 being also considerable.

The experiments in the present paper suggest that the fixation of phosphates by the soil takes place in three stages. A tentative suggestion can be offered based on the idea of Mattson and Karlson [1938]*. The PO_4 ions which come out of the soil in the first extraction is a measure of the 'extra-micellar' PO_4. The sum total of those which comes out in subsequent extractions is a measure of the 'saloid-bound' PO_4, and the phosphate which remains permanently fixed measures the 'colloid-bound' phosphate. This grouping of absorbed phosphates into three categories is similar to the ideas of Heck [1934].

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* The idea of micellar-binding of PO_4 ions is similar to the considerations put forward by Mukherjee as early as 1921 [Mukherjee, 1921].

Tables IV and V show the comparison between the quantity of P fixed by ignited and non-ignited soils. It will be found that there is no general correlation between the quantity of phosphates fixed by non-ignited and ignited soils.

Table VI shows the relation between p.p.m. of P fixed by the non-ignited soils and percentage sesquioxides in hydrochloric acid extracts [Van Bemmelen, 1877 *et seq.*]. The p.p.m. of P fixed as shown by the first extraction was plotted against the percentages of sesquioxides in HCl extract (Fig. 1). It will be seen from the curve that, in general, the p.p.m. of phosphorus fixed increases with the percentages of sesquioxides in HCl extract. Similar observations have also been made by Romine and Metzger [1939].

TABLE IV

Amount of P coming into solution when the phosphate-treated non-ignited soil is shaken with 0·002 N *sulphuric acid solution*

Locality	Soil No.	Depth	p.p.m. of P coming into solution from the treated soil less p.p.m. of P coming into solution in each corresponding extraction from the untreated soil (500 p.p.m. of P was added)				
			1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Dacca Farm (Bengal)	1p	0–6 in.	252	52	35	32	371
	2p	6 in.—2 ft. 3 in.	193	61	45	23	322
	3p	2 ft. 3 in.—4 ft.	148	111	48	43	350
Himayatsagar (Hyderabad)	18p	0—3 in.	311	62	35	25	433
	19p	3 in.—1 ft. 6 in.	252	64	45	44	395
	20p	1 ft. 6 in.—4 ft.	323	75	17	29	444
	21p	1 ft. 6 in.—4 ft.	405	36	11	9	461
Telankheri (1), Nagpur (C. P.)	23p	0—2 ft.	85	62	56	29	232
	24p	2 ft.—2 ft. 6 in.	68	55	48	40	211
Telankheri (2), Nagpur (C. P.)	26p	13 ft.—16 ft.	450	1	17	26	494
	27p	16 ft.—21 ft.	397	33	9	31	407
Chandkhuri Farm, Raipur (C. P.)	33p	0—4 in.	236	66	48	48	398
	34p	4 in.—1 ft. 5 in.	160	89	60	42	351
	35p	1 ft. 5 in.—4 ft.	178	90	56	50	374
Puzathi, Cannanore (Madras)	48p	16 ft.—30 ft.	200	97	49	9	355
	50p	Below 30 ft.	342	46	40	5	433
	51p	Below 30 ft.	383	51	52	50	486
Nilgiri hills (1), (3,000 ft. a. s. l.)	53p	0—1 ft. 8 in.	216	51	53	45	365
	54p	1 ft. 8 in.—3 ft.	205	54	59	43	361
	55p	Below 54p	219	87	49	36	391
Nilgiri hills (2), (5,000 ft. a.s. l.)	56p	0—1 ft. 2 in.	94	53	40	34	221
	57p	1 ft. 2 in.—2 ft.	71	61	41	34	207
	58p	2 ft.—6 ft.	141	102	86	79	308

TABLE IV—*concld.*

Locality	Soil No.	Depth	p.p.m. of P coming into solution from the treated soil less p.p.m. of P coming into solution in each corresponding extraction from the untreated soil (500 p.p.m. of P was added)				
			1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Nilgiri hills (3), (7,000 ft. a. s. l.)	59p	0—1 ft.	116	84	46	45	291
	60p	1 ft.—3 ft.	12	19	26	24	81
	61p	3 ft.—4 ft. 6 in.	38	48	40	38	164
	62p	4 ft. 6 in.—6 ft.	36	46	43	18	143
Stambhalaguruva, Guntur (Madras)	67p	0—8 in.	299	41	27	33	400
	68p	in.—1 ft. 2 in.	231	50	57	3	331
	69p	1 ft. 2 in.—5 ft.	265	164	36	28	493
Hathwara, Manbhum, Chota Nagpur (Orissa).	81p	0—1 ft. 6 in.	240	62	41	41	384
	82p	1 ft. 6 in.—2 ft. 3 in.	166	69	62	46	343
	83p	2 ft. 3 in.—3 ft. 6 in.	125	67	58	36	376
	84p	3 ft. 6 in.—4 ft. 11 in.	117	59	57	41	274
	85p	Below 4 ft. 11 in.	242	51	50	36	379
Kapileswar, Bhubaneswar (Orissa)	103p	0—2 ft. 11 in.	179	80	63	54	376
	104p	2 ft. 11 in.—4 ft.	171	86	57	41	355
	105p	Below 4 ft.	286	61	29	33	409
Lalgarh, Midnapur (Bengal)	112p	0—4 in.	213	145	82	46	486
	113p	4 in.—3 ft. 4 in.	196	102	90	49	437
	114p	3 ft. 4 in.—4 ft.	275	71	49	31	426
	115p	7 ft.—8 ft.	236	59	42	39	376
Black cotton soils	114	...	251	123	84	34	492
	118	...	123	170	115	43	451
	119	...	294	38	16	27	377
Kaolin (American)	...	...	386	49	24	24	483
Kaolin (Indian)	...	...	382	37	23	23	463
Bauxite (American)	...	...	193	61	50	25	329
Bauxite (Indian)	...	...	180	50	41	14	285
Limonite	...	...	248	26	20	19	313
Magnetite	...	...	260	21	20	19	320
Haematite	...	...	213	12	11	6	242
Ilmenite	...	...	90	18	17	6	131
Iron oxide gel	...	...	0	0	0	0	0
Alumina gel	...	...	65	50	35	30	180
Titania gel	...	...	0	0	0	0	0
Silica gel	...	...	315	52	37	15	419

TABLE V

Amount of P coming into solution when the phosphate-treated ignited soil is shaken with 0·002 N *sulphuric acid solution*

Locality	Soil No.	p.p.m. of P coming into solution from the treated soils less p.p.m. of P coming into solution in each corresponding extraction from the untreated soil (500 p.p.m. of P was added).				
		1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Dacca Farm (Bengal)	1p	273	98	36	21	427
	2p	275	69	31	31	406
	3p	222	96	82	48	448
Himayatsagar (Hyderabad)	18p	189	66	37	20	312
	19p	186	105	53	32	376
	20p	305	172	112	5	494
	21p	212	57	25	21	315
Telankheri (1), Nagpur (C. P.)	23p	264	89	35	48	436
	24p	217	50	35	30	332
Telankheri (2), Nagpur (C. P.)	26p	468	19	10	2	499
	27p	387	50	11	10	458
Chandkhuri Farm, Raipur (C. P.)	33p	248	99	56	31	424
	34p	210	100	47	45	402
	35p	100	98	69	59	326
Puzathi, Cannanore (Madras)	48p	274	72	36	35	417
	50p	318	65	45	35	460
	51p	308	80	20	12	420
Nilgiri hills (1) (3,000 ft. a. s. l.)	53p	224	61	28	21	334
	54p	222	64	49	46	381
	55p	279	63	41	41	424
Nilrgil hills (2) (5,000 ft. a. s. l.)	56p	144	76	45	34	299
	57p	98	48	51	45	242
	58p	150	94	51	41	316
Nilgiri hills (3), (7,000 ft. a. s. l.) (Madras)	59p	120	72	58	49	299
	60p	80	86	72	44	282
	61p	70	76	72	58	276
	62p	125	98	65	44	332
Stambhalaguruva, Guntur (Madras)	67p	243	40	62	0	345
	68p	246	43	30	29	347
	69p	240	50	50	20	360

TABLE V—*contd.*

Locality	Soil No.	p.p.m. of P coming into solution from the treated soils less p.p.m. of P coming into solution from the untreated soil in each corresponding extractions (500 p.p.m. of P was added)				
		1st extraction	2nd extraction	3rd extraction	4th extraction	1st + 2nd + 3rd + 4th extractions
Hathwara, Manbhum (Bihar)	81p	198	68	52	43	361
	82p	253	40	50	37	380
	83p	181	45	42	37	304
	84p	135	86	52	37	310
	85p	236	85	43	35	399
Kapileswar, Bhubaneswar (Orissa)	103p	337	65	42	34	478
	104p	216	87	48	39	390
	105p	296	59	25	30	410
Lalgarh, Midnapur (Bengal)	112p	221	98	76	67	462
	113p	229	54	37	43	364
	114p	278	49	50	49	426
	115p	263	49	48	36	396
Black cotton soils	114	203	67	62	60	392
	118	124	109	61	36	330
	119	218	105	35	30	368
Kaolin (American)*		380	78	25	10	493
Kaolin (India)		380	39	25	25	469
Bauxite		190	60	52	27	329
Limonite		250	24	20	19	313
Magnetite		262	19	19	18	313
Haematite*		200	18	17	9	244
Ilmenite		85	27	20	9	141

* Chemical compositions of these minerals are as follows :—

	SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	TiO_2 per cent	P_2O_5 per cent
Kaolin (American)	38·69	11·88	0·10	0·60	0·00
Haematite	0·57	7·52	91·32	0·57	0·00

TABLE VI

Relation between p.p.m. of P fixed in the soil and percentage of sesquioxides in hydrochloric acid extracts

Soil No.	p.p.m. of P fixed as shown by 1st extraction	p.p.m. of P fixed as shown by 4 extractions	Percentage sesquioxides in HCl extract**
1p . . .	248	129	20·50
2p . . .	307	178	12·84
3p . . .	352	150	19·13
18p . . .	189	67	9·75
19p . . .	148	105	7·08
20p . . .	177	56	11·03
21p . . .	95	19	15·41
23p . . .	415	268	43·77
24p . . .	432	289	43·26
26p . . .	50	6	20·00
27p . . .	103	30	26·29
33p . . .	264	102	44·67
34p . . .	340	149	46·68
35p . . .	322	126	56·90
48p . . .	300	145	16·62
50p . . .	158	67	6·03
51p . . .	167	14	7·62
53p . . .	284	135	20·28
54p . . .	295	139	22·29
55p . . .	281	109	19·95
56p . . .	406	229	24·56
57p . . .	419	293	18·72

** These values include the percentages of TiO_2 and P_2O_5 in the HCl extract besides those of Al_2O_3 and Fe_2O_3.

TABLE VI—*contd.*

Soil No.	p.p.m. of P as shown by 1st extraction	p.p.m. of P as shown by 4 extractions	Percentage sesquioxides in HCl extract
58p . . .	359	192	7·92
59p . . .	384	209	37·58
60p . . .	488	419	52·58
61p . . .	462	336	54·84
62p . . .	464	357	45·69
67p . . .	201	100	9·65
68p . . .	269	169	17·55
69p . .	235	7	19·67
81p . . .	260	116	8·09
84p . . .	383	226	13·30
85p . . .	258	121	15·83

Practical aspect of fixation of phosphates

While the subject of phosphate fixation is important from theoretical considerations, indicating the nature of the fixation, it has its practical applications. The fundamental question with which the common agriculturist is concerned is the determination of the minimum amount of phosphatic fertilizers necessary to add to a particular soil in order to establish and maintain in the soil solution a concentration of phosphate sufficient to meet the needs of the standing crop. The chief interest of the farmer, therefore, centres round the determination of that portion of a standard phosphate treatment which remains unfixed or, being fixed, is yet able to rapidly re-enter the soil solution as the nutrient is withdrawn from the medium by the roots of the standing crop. Phosphate fixation in a moderate degree may indeed be looked upon as a benefit to the farmer, for it then becomes a means of withholding the nutrient against leaching. When, however, fixation is excessive an application of water-soluble phosphates becomes so firmly held in the soil that plants may have difficulties in obtaining quantities required for their growth and development. It is clear that so far as crop production is considered, phosphate fixation is not invariably an unmitigated evil.

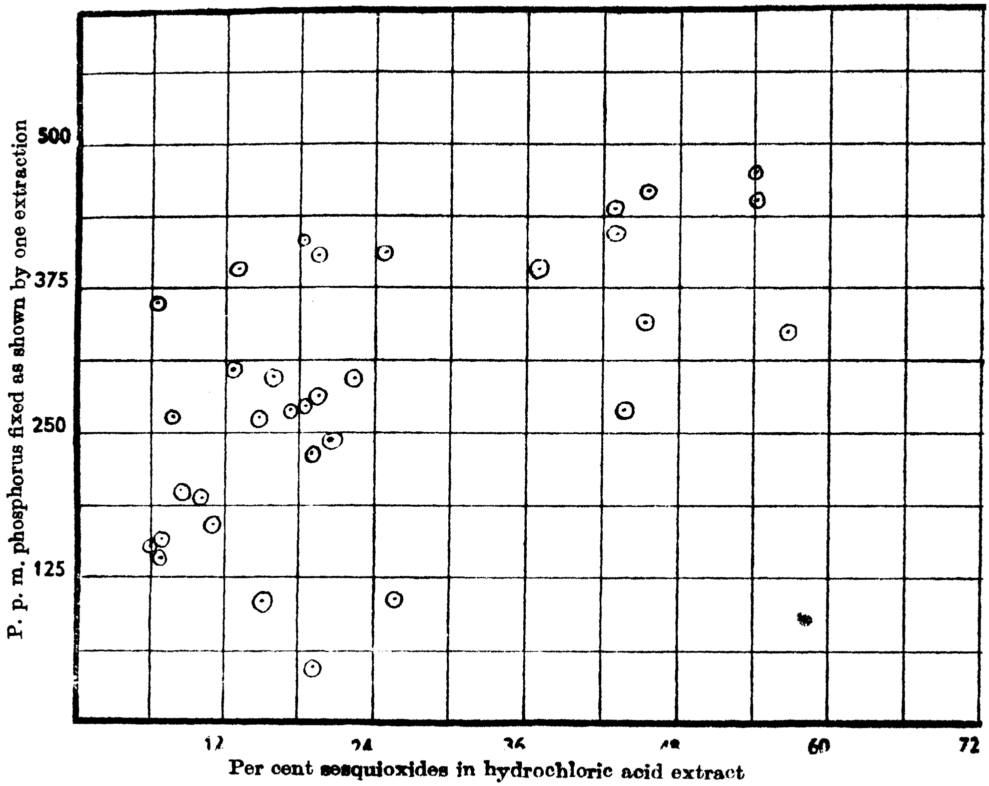

FIG. 1. Variation of the p.p.m. of phosphorus fixed in the soils (as shown by one extraction) with the percentages sesquioxides in hydrochloric acid extracts (vide Table VI)

Summary

1. Fixation of phosphates by Indian red soils has been studied from two points of view :—

Section I.—Section I deals with a study on the uptake of phosphates from phosphate solutions by soils after shaking the mixture of the soil and the phosphate solution for a certain time.

Section II.—This section deals with a study on the fixation of phosphates by soils from phosphate solutions when the latter are brought into equilibrium with the soil by evaporation to dryness.

2. It is found, in general, that up to about 30 minutes time of shaking, the phosphate fixation proceeds at a rapid rate, the rate gradually falling off, becoming almost constant after two hours and remaining thus for the remainder of the period during which observations were made.

3. When equilibrium is brought about by shaking, it is found that Indian bauxite possesses the maximum power of retention of phosphates, whilst kaolin possesses none. The capacity of magnetite to retain phosphate is not appreciable, whilst the hydrated iron-bearing mineral limonite, and the

titanium-bearing mineral ilmenite possess almost the same power of retaining phosphates.

4. The absorption of phosphates by shaking is highest in the case of the profile samples from Nilgiri hills (2) and Nilgiri hills (3), and is considerably greater than in the case of ordinary iron-bearing or titanium-bearing minerals.

5. When equilibrium is brought about by evaporation of the mixture to dryness, ilmenite shows maximum power of phosphate fixation, next in order being haematite. Of the gels studied, Fe_2O_3 and TiO_2 possess a very high power of phosphate fixation and that by Al_2O_3 is also considerable.

6. There is no correlation between the quantity of phosphate fixed by ignited and non-ignited soils.

7. In general, the p.p.m. of phosphorus fixed increases with the percentage of sesquioxides in hydrochloric acid extract of the soils.

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REFERENCES

Bradfield, R.; Scarseth, G. and Steele, J. G. (1935). *Trans. 3rd Internat. Cong. Soil Sci.* **1**, 74-5
Dean, L. A. (1934). *Soil Sci.* **37**, 253-66
Ford, M. C. (1933). *J. Amer. Soc. Agron.* **25**, 134-44
Fraps, G. S. (1922). *Texas Agric. Exp. Sta. Bull.* **304**
Hance, F. F. (1933). *Hawai. Plant. Rec.* **37**, 182-96
Hardy, F. and Follettsmith, R. R. (1931). *J. Agric. Sci.* **21**, 150-66
Heck, A. F. (1934). *Soil Sci.* **37**, 477-82, 874-84
Mattson, S. and Karlson, N. (1938). *Annals Agric. Coll. Sweden* **6**, 109
Mukherjee, J. N. (1921). *Trans. Far. Soc.* **16**, 103-15
Romine, D. S. and Metzger, W. H. (1939). *J. Amer. Soc. Agron.* **31**, 99-108
Truog, E. (1930). *J. Amer. Soc. Agron.* **22**, 874-82
Truog, E. and Meyer, A. H. (1929). *Indus. and Eng. Chem. Anal. Ed.* **1**, 136-S
Van Bemmelen, J. M. (1877). *Landw. Versuch Stat.* **21**, 135-91
——————(1879). *Landw. Versuch Stat.* **23**, 265-303
——————(1888). *Landw. Versuch Stat.* **35**, 69-136
——————(1904). *Ztsch. Anorg. Chem.* **42**, 265-314

STUDIES ON INDIAN RED SOILS

III. GENERAL MORPHOLOGICAL CHARACTERISTICS OF SOME PROFILES

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IN connection with the investigations at the Dacca University, on the nature of red soils of India, financed by the Imperial Council of Agricultural Research, monoliths and profile samples were collected from Chota Nagpur, Orissa, Assam, Bengal and southern India. In selecting the sites care was taken to obtain the most representative red soils of the locality. Profiles from the places enumerated below have been examined, and those marked with asterisk as representing typical areas have been described and discussed in the present paper.

A. CHOTA NAGPUR
  1. Hathwara Farm, Purulia, Manbhum
  *2. Putida, Chybasa, Singhbhum (Table I)
  3. Ratu, Ranchi
  *4. Baralota, Daltonganj, Palamau (Table II)

B. ORISSA
  5. Tangi, Kapilas Road, Cuttack
  6. Dhanmandal, Cuttack
  *7. Kapileswar, Bhubaneswar (Table III)
  *8. Jhinkartangi, Khurda town (Table IV)

C. ASSAM
  *9. Mawphlang, Khasi hills (Table V)
  10. Cherrapunji, Khasi hills
  11. Burrabazar, Khasi hills, Shillong
  *12. Upper Chandmari, Tura, Garo hills (Table VI)
  *13. Nongpoh, Khasi hills (Table VII)
  14. Uzanbazar, Gauhati
  15. Divisional Forest Office compound, Tura, Garo hills
  16. Babupura, Tura, Garo hills

D. BENGAL
  *17. Lalgarh, Midnapur (Table VIII)
  18. Khudsoule Mouza, Bankura
  *19. Sultanganj, Bogra (Table IX)
  20. Khetur Road, Barind Tract, Rajshahi
  21. Bhowal Gajari Garh, Jaydebpur, Dacca

E. SOUTHERN INDIA
  *22. Sankey's Tank area, Bangalore (Table X)

23. Navayur, Coimbatore
24. Sravanampatti, Hillock, Coimbatore (Black cotton soil)
25. Sravanampatti Hillock, Coimbatore (Red soil)
26. Kadirur village, Tellicherry, Malabar
*27. Talap village, Cannanore, Malabar (Table XI)
*28. Pasumalai, Madura (Table XII)
29. Maddilipalayam village, Vizagapatam (Grey soil)
30. Maddilipalayam village, Vizagapatam (Red soil)

} Madras province

DESCRIPTIONS OF TYPICAL RED SOIL FROM VARIOUS TRACTS

A. SOILS OF CHOTA NAGPUR

The soils of the plateau of Chota Nagpur have been formed on various types of rocks, the most commonly occurring types being unclassified crystalline gneiss. As Schokalsky [1932] has pointed out, the original gneiss of Chota Nagpur and the rocks of other ages, occurring in some places of the plateau, are overlaid by red soil, the greater part of which is of a sandy clayey composition. On the flat-topped summits maize, millets and pulses are cultivated. The slopes are worked into many terraces, and well-irrigated rice may be cultivated on these and also in valleys. It was found on the whole that the red soils occurring in the different districts of Chota Nagpur are very similar. The coarse, gritty red soil is frequently quarried for making roads and roofs of houses. In general red soils are found to exist on the higher slopes of hills, brownish soils at intermediate layers and blackish soils lower down. The blackish soil is suitable for cultivation and crop production. Throughout the range of Chota Nagpur considerable gully and sheet erosion are noticeable.

TABLE I

Soil profile No. P (D. U.) 33 Put.

1. *Locality* : Putida (Chybasa), Singhbhum, Chota Nagpur
2. *Climate*—
   Temperature : Maximum 115°F. (end of May) ; minimum 85°F. (end of December)
   Rainfall (in.) : Jan. 0·64, Feb. 1·68, Mar. 0·69, Apr. 0·89, May 1·77, June 4·45, July 10·67, Aug. 13·04, Sept. 7·65, Oct. 2·39, Nov. 1·33, Dec. 0·34 : Total 45·54.
3. *Altitude* : 762 ft. a. s. l.
4. *Surface feature* : Undulating. Profile was taken on a mild slope. On the northern side of the pit is Munduburn hills
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Thin grass, *palash*, *biri* leaf, *asan* tree, *mahua* (*Bassia latifolia*)
   Common crops : Sugarcane, *aman* paddy, groundnut, maize, soyabean, gram, wheat
6. *Soil-water conditions*—
   Free surface drainage at the place where the profile was taken, but in adjacent areas waterlogging was observed
   Water table : Maximum depth, 18 ft. in summer ; minimum depth 14 ft. in rainy season

7. *Character of parent material* : Dalma trap and Mergui volcanics

Horizon	Thickness	Description of each horizon			Sapmle depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. .	Greyish black	Sandy loam .	Friable and granular	0-1 ft. .	Greyish black soil mixed with gravels and boulders with interpenetration of plant roots, mixed with yellowish clay-like material
2	1 ft.-2 ft. 9 in.	Reddish .	Clayey loam	Granular .	1 ft.-2 ft. 9 in.	Concretionary layer mixed with boulders and gravels
3	Below 2 ft. 9 in.	Yellowish red	Rocky .	Honeycombed and compact	2 ft. 9 in.-4 ft.	Rocky material often containing yellowish substances, entrapped in the vesicles and considerable quantities of dark reddish pieces of slate-like material

TABLE II

Soil profile No. P (D. U.) 35 Bar.

1. *Locality* : Baralota, Daltonganj, Palamau district, Chota Nagpur
2. *Climate*—

Temperature : Maximum 115°F. (end of May); minimum 85°F. (end of December)

Rainfall (in.) : Jan. 0·99, Feb. 1·28, Mar. 0·37, April 0·43, May 0·59, June 3·39, July 15·53, Aug. 13·29, Sept. 5·91, Oct. 2·33, Nov. 0·75, Dec. 0·36 : Total 45·22

3. *Altitude* : 726 ft. a. s. l.
4. *Surface features* : Undulating. Profile taken on a gentle slope
5. *Nature of natural and cropping vegetation*—

Natural vegetation : *Palash* and *sal* trees

Crops :

(*a*) Monsoon—Paddy, maize, *rahar* (*Cajanus cajan*), and groundnut

(*b*) *Rabi*—Wheat, gram, barley

6. *Soil-water conditions*—

Free surface drainage

Water table : Maximum depth 35-40 ft. in summer ; minimum depth 20-25 ft. in rainy season

7. *Character of parent material* : Limestones, shales and slates

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. 1 in. .	Dark red .	Clayey .	Loose granular	0-1 ft. 1 in. .	Dark red soils mixed with gravels
2	1 ft. 1 in.-2 ft. 9 in.	Red . .	Clayey .	Gritty . .	1 ft. 1 in.-2 ft. 9 in.	Red soil mixed with large quantities of pebbles and concretionary materials
3	2 ft. 9 in.-4 ft.	Red . .	Sandy loam	Gritty . .	2 ft. 9 in.-4 ft.	Ditto, but more compact
Sample from another place in the vicinity from where it was already quarried						
4	4 ft.-5 ft. .	Yellow.	Sandy . .	Loose . .	4 ft.-5 ft. .	Yellowish sandy material with admixtures of whitish substance

B. Soils of Orissa

The province of Orissa including the Mahanadi river delta represents an absolute flatness, coated with alluvial deposits. The alluvial bed, red in colour, in some places rests on low-level laterite. An inspection of several areas suggests that the soils of the province of Orissa belong at some places to the red and some places to the lateritic varieties, generally low-level laterites.

Table III

Soil profile No. P (D. U.) 38 Kap.

1. *Locality* : Kapileswar village, 1 mile west of Bhubaneswar town
2. *Climate*—
   Temperature : Maximum 106°F.-110°F. (3rd week of May) ; minimum 52°F. (end of December)
   Rainfall (in.) : Jan. nil, Feb. 4·26, Mar. 1·52, Apr. 2·00, May 3·60, June 5·87, July 22·17, Aug. 12·28, Sept. 12·53, Oct. 3·60, Nov. nil, Dec. nil : Total 67·83
3. *Altitude* : 108 ft. a. s. l.
4. *Surface feature* : Undulating, the profile taken in a quarry on a gentle slope from Udaygiri to Gogua rivulet
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Nux-vomica, banian, mangoes, *pipal* (***Ficus religiosus***), *madan masta*
   Crops : Paddy, *mung* (***Phaseolus radiatus***), arum, sugarcane
6. *Soil-water conditions* —
   Free surface drainage and free percolations through the laterite stones
   Water-table : Maximum depth 25 ft. in summer ; minimum depth 6 ft. in rainy season
7. *Character of parent material* : Gneiss

Horizon	Description of each horizon				Sample depth	Remarks
	Thickness	Colour	Texture	Structure		
1	0-2 ft. 11 in.	Reddish brown	Loamy	Loose granular	0-2 ft. 11 in.	Soil mixed with root and pebbles, the colour of the soil becoming gradually deeper red from top downwards
2	2 ft. 11 in. below (up to 30 ft.approx.)	Bright red, mottled with yellow, white and black	Rocky	Honeycombed	2 ft. 11 in.-4 ft.	Honeycombed laterite rock with yellow and white clay material entrapped in the vesicles
Sample from another place from the digging of a well						
3	30 ft. downwards	Whitish clayey	...	...	...	Locally known as '*tilak mati*' (used in painting foreheads)

TABLE IV

Soil profile No. P (D. U.) 39 Jhin.

1. *Locality* : Jhinkartangi, 2 miles south of Khurda town
2. *Climate* —
   Temperature : Maximum 106°F. (3rd week of May) ; minimum 50°F. (end of December)
   Rainfall (in.) : Jan. 0·40, Feb. 0·74, Mar. 0·90, April 0·81, May 3·35, June 9·04, July 12·89, Aug. 12·84, Sept. 10·14, Oct. 6·05, Nov. 1·76, Dec. 0·37 : Total 59·29
3. *Altitude* : 50 ft.-100 ft. a.s.l.
4. *Surface features* : Profile taken from a quarry on the top of a ridge called 'Jhinkar Tangi' on the northern side of the Barunai Hill and close to the hill
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Nux-vomica, *kendu*, mango, jak tree, tamarind, banian, *peepal*, plum
   Cropping vegetation : Paddy, *mung*, *kalai*, lentil, sugarcane, *rahar*, *kulthi*, potato, pumpkin, *karela*
6. *Soil-water conditions*—
   Free surface drainage and impeded percolation in the stony layers. The top soil always permits free percolation
   Water-table : Maximum depth 20 ft. in summer ; minimum depth 0 ft. in the rainy season
7. *Character of the parent material* : Gneiss

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. . .	Brownish red	Clayey loam .	Loose granular	0-1 ft. . .	Soil mixed with gravels
2	1 ft.-2 ft. .	Ditto (the reddish tinge being deeper than in the 1st layer)	Do. .	Do. .	1 ft.-2 ft. .	Do.
3	2 ft.-8 ft. 6 in.	Bright red .	Do. .	Gravelly .	2 ft.-8 ft. 6 in.	Laterite murrum
4	8 ft. 6 in. below	Red mottled with yellow and whitish colour	Rocky .	Honeycombed laterite rock	8 ft. 6 in.-10 ft.	The top 6 in. of the laterite rock is softer and easier of cutting than of the bottom which gradually becomes harder as the depth increases
Sample from another place from the digging of a well						
5	30 ft.-50 ft. .	Yellow .	Clayey .			
6	50 ft. below .	White . .	Clayey			

The two types of laterites occur in these places : firstly the type of laterite murrum and secondly the type of laterite rock. The former is quarried for the construction of roads and roofs and the latter for cutting into the forms of bricks (usually 9 in. × 15 in. × 24 in. slabs) for the construction of buildings. The soft laterite murrum contains considerable quantities of plant food materials and has often been found quite suitable for the growth of paddy, oranges and roses. A well (45 ft.) dug in the Khurda Forest Office (Puri district) showed soil characteristics as follows :—

1. 0-15 ft.—A layer of red laterite murrum
2. 15-30 ft.—Red honeycombed laterite rock
3. 30-32 ft.—Yellow clay
4. 32-35 ft.—White clay
5. 35-45 ft.—Clay of deep grey colour

The reddish honeycombed laterite rocky mass turns black after exposure to the sun for some time. The depth of the laterite murrum layers varies at different places considerably. So also do the layers of hard laterite and yellow, white and cement-coloured clays. In fact some of the layers are entirely absent from some of the places.

As in the case of Bihar, considerable gully and sheet erosion was noticeable in Orissa.

At Khurda town the higher plots were found to be mostly sandy at the top and clayey underneath, some plots having hard rock beds on the surface. Consequently these lands sometimes become impervious to agricultural implements and have very low moisture-retention capacities. They are practically worthless for cultivation, especially during hot weather, though paddy may be grown to some extent during the rains.

SOILS OF ASSAM

The Shillong plateau (Khasi and Jaintia hills)

The Shillong plateau rises steeply from the Surma valley to an average height of 4,000 ft. and gradually slopes towards the Brahmaputra valley in a succession of low ranges covered with dense evergreen forests. Even in the hottest weather, the temperature of Shillong never records above 80°F., and there is often frost in winter. Snowfall is rare, because there is no precipitation of moisture in the cold season. The average rainfall of Shillong town is 80 in. per year. On the other hand, at Cherapunjee, a station on the southern end of the Khasi hills, about 30 miles from Shillong, the average annual rainfall is 426 in. The general characteristics of soil types in the Khasi hills are of red soils on the top of hills, yellowish soils at intermediate layers and black soil at the bottom.

In Cherapunjee, in most places, sandstone occurs below the surface up to 20-25 ft. approximately. Frequently the sandstone occurs as outcrops, and even in sandy soil moisture is retained. Below the sandstone layer, at depths approximately 35-40 ft. below the surface, limestone frequently occurs, whilst at some places near the surface, deposits of coal occur up to 3 ft. depth.

Near about the Shillong plateau below the hard soil layer honeycombed laterite rocky mass is however fairly soft. Pieces of boulders, mostly composed of granites are very common in all places of the Khasi hills. Soil erosion occurs extensively.

To quote the words of Schokalsky [1932], 'The Shillong plateau is composed of Archean quartzites and schists, interstratified with trap and overlaid by sandstones of the cretaceous period, which in their turn dip under eocene nummulitic limestone. In origin the plateau is more closely allied to the Deccan than to the Himalayas ; it is supposed to be a part of the Deccan, precisely the north-east extremity of the latter, which was afterwards separated from it by the subsidence of Bengal. This view is confirmed by its gneisses and schists extending throughout the latter, as well as Bihar, Orissa, etc. And in the character of its soils, Shillong belongs to the Deccan. Under the conditions of a tropical humid climate on the plateau corresponding soil types should develop '.

The soils on the Shillong plateau are generally known as lateritic. But on a considerable area of the plateau nummulitic limestones form the upper layer of the sediments. In such areas we should be inclined to presume the occurrence of red soil, in places which are not infrequently developed from the products of decomposition of limestone [Schokalsky, 1932]. South of the Shillong plateau extends a vast area known as Madhupur jungle ; Oldham [1893] holds the view that it is composed of alluvial red-coloured clays.

Coal, limestone and iron are the principal minerals found in Khasi and Jaintia hills. Cretaceous coal is found near Mawphlang, tertiary coal in Cherra, and limestone is found on the surface of Khasi and Jaintia hills, especially at Khasimora on the south slopes of the Khasi hills. Corundum is also found in the district in small quantities. Iron is available at Cherra and Lylinkot. Mineral oil has been found near Cherra.

The flora of the Khasi hills is extremely rich and has a luxuriant growth. Hooker [1854] collected, within 10 miles of Cherra, over 2,000 flowering plants, with varieties of orchids, balsams and wild roses.

Paddy and potatoes grow very well in the Khasi and Jaintia hills. Cotton, however, does not do so well.

Garo hills

The soil types in the Garo hills, from the morphological point of view, appear to be different from the typical lateritic soils of Orissa. It appears that the removal of clayey matter by erosion from the soil types is the cause of the sandy nature of the soil. The white sandy material of the soil seems to be contaminated with substances of the nature of kaolin which makes this white material a valuable substance for the construction of roads.

Various types of red soils * occur at different places in the Garo hills area most of which are sandy in nature. In the Government Farm areas cowdung is usually applied as manure. Ordinary cultivators, however, do not apply any manure, and after one or two years, they find the land unproductive and shift to another place.

Common crops grown in the Garo hills are maize, rice, cotton, and chilli. Pineapples also grow very well. The usual method of farming in the Garo hills is what is known as *jhum* cultivation, i.e. cutting of the forest and setting fire to the trees. When the jungles have been cleared in this way any of the above crops can be grown. After two years of crop production, however, the land becomes unproductive, and it appears that instead of keeping the land fallow, as is usually done, the production of leguminous crops, like pulses, might increase the productivity of the land.

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* The local name for the red soil is *agichak*

TABLE V

Soil profile No. P (D. U.) 41 Kha.

1. *Locality* : Mawphlang, Khasi hills, Assam
2. *Climate*—
   Temperature : Maximum 80°F. (March-April) ; minimum 24°F. (Dec.-Jan.)
   Rainfall (in.) : Jan. 0·52, Feb. 1·04, Mar. 2·17, April 5·24, May 11·14, June 34·88, July 34·00, Aug. 22·52, Sept. 15·86, Oct. 9·55, Nov. 1·49, Dec. 0·26 : Total 138·67
3. *Altitude* : 6,000 ft. a.s.l.
4. *Surface features* : Sloping towards south
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Pine, wild oak, rhododendrons
   Cropping vegetation : Potatoes, maize, millets, soy-bean
6. *Soil-water conditions* : Free surface drainage
7. *Character of parent material* : Shillong series

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-6 in.	Brownish grey	Loamy	Loose granular	0-6 in.	Interpenetration of roots
2	6 in.-1 ft. 3 in.	Reddish grey	Loamy	Do.	6 in.-1 ft. 3 in.	Do.
3	1 ft. 3 in.-2 ft. 1 in.	Red	Stiff clayey	Granular	1 ft. 3 in.-2 ft. 1 in.	Mixed with some whitish materials. Occasionally some burrow holes were noticed. The soil remains moist even in dry weather.
4	2 ft. 1 in.-4 ft.	Deep red	...	..	2 ft. 1 in.-4 ft.	Mixed with concretionary compact materials, intermingled occasionally with whitish material.
5	Parent materials	...	...	...	... ...	Pieces of sandstone, quartz, and iron concretions.

TABLE VI

Soil profile No. P (D. U.) 44 Kha.

1. *Locality* : Nongpoh district, Khasi and Jaintia hills, Assam
2. *Climate.*—
   Temperature : Maximum 77°F.-84°F. (April-Sept.) ; minimum 57°F.-58°F. (Dec.-Jan.)
   Rainfall (in.) : Total 70 in. approximately
3. *Altitude* : 1,800 ft. a. s. l.
4. *Surface features* : Undulating, profile taken from a cutting on a hilly slope
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Sal, poma, *Ficus* (different kinds), plantains
   Cropping vegetation : Paddy, cotton, pulses

Soil-water conditions : Free surface drainage

7. *Character of parent material* : Granites

Horizon	Description of each horizon				Sample depth	Remarks
	Thickness	Colour	Texture	Structure		
1	0-6 in.	Reddish grey	Loamy	Granular	0-6 in.	Penetration of roots
2	6 in.-3 ft. 6 in.	Yellowish red	Loamy	Columnar	6 in.-3 ft. 6 in.	Containing small iron nodules
3	3 ft. 6 in.-4 ft. 2 in.	Blackish red	Clayey	Concretionary	3 ft. 6 in. 4 ft. 2 in.	Soft concretions
4	4 ft. 2 in.-6 ft.	Red	Clayey	Do.	4 ft. 2 in.-6 ft.	Do.
5	Parent material	...	...	...	...	Granites

TABLE VII

Soil profile No. P (D. U.) 46 Gar.

1. *Locality* : Upper Chandmari, Tura, Garo hills, one mile north of Inspection Bungalow
2. *Climate*—
   Temperature : Maximum 85°F.-87°F. (March-September) ; minimum 53°F.-54°F. (January)
   Rainfall (in.) : Jan. 0·41, Feb. 0·89, Mar. 2·09, April 6·92, May 16·36, June 25·39, July 24·81, Aug. 21·87, Sept. 19·18, Oct. 8·25, Nov. 0·73, Dec. 0·11 : Total 127·01
3. *Altitude* : 1,300 ft. a.s.l.
4. *Surface features* : Hilly and undulating, profile taken on the slope of a hillock
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Sal, bamboo, tamarind, mango, jak fruit
   Cropping vegetation : Cotton, paddy, chilli, maize
6. *Soil-water conditions*—
   Free surface drainage
   Water-table : Maximum depth 10-12 ft. in dry season ; minimum depth 3-4 ft. in wet season
7. *Character of parent material* : Pab sandstones

Horizon	Description of each horizon				Sample depth	Remarks
	Thickness	Colour	Texture	Structure		
1	0-3 in.	Grey	Sandy	Nutty and friable.	0-3 in.	Penetration of roots
2	3 in.-1 ft. 8 in.	Grey mixed with mottled red	Sandy	Friable	3 in.-1 ft. 8 in.	Easily crumbles down, mixed with whitish material
3	1 ft. 8 in.-2 ft. 8 in.	Light red mixed with black and white	Sandy	Friable rocky mass	1 ft. 8 in.-2 ft. 8 in.	Seems to be of the nature of dead rocks
4	2 ft. 8 in.-4 ft.	White mixed with (occasionally) black and pinkish matter	Sandy	Crumbly rocky mass	2 ft. 8 in.-4 ft.	Mixed with quartz particles

SOILS OF BENGAL

(*i*) *Western Bengal*

TABLE VIII

Soil profile No. P (D. U.) 40 Lal.

1. *Locality* : Lalgarh, 27 miles N.-N.-W. of Midnapur
2. *Climate*—
   Temperature : Maximum 100°F.-105°F. (last week of April) ; minimum 45°F.-50°F. (first week of January)
   Rainfall (in.) : Jan. 1·31, Feb. 0·80, Mar. 0·45, April 1·62, May 0·54, June 6·69, July 7·98, Aug. 6·97, Sept. 4·35, Oct. 2·63, Nov. 1·65, Dec. 0·68 : Total 34·67
3. *Altitude* : 239 ft. a.s.l.
4. *Surface features* : Undulating ; profile taken on a mild slope
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Shrubby weeds, lantana plants are common
   Cropping vegetation : Aus and aman paddy, castor, maize and *juar*
6. *Soil-water conditions*—
   Free surface drainage, impeded percolation
   Water-table : Maximum depth 100 ft. in summer ; minimum depth 10 ft. in rainy season
7. *Character of parent material* : Cuddalore, warkalli, karewa, older alluvium, laterite

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-4 in. . .	Brownish red	Sandy loam .	Loose laterite murrum	0-4 in. . .	Gravelly
2	4 in.-3 ft. 4 in.	Yellowish red	Rocky .	Compact laterite murrum	4 in.-3 ft. 4 in.	Compact and gravelly
3	3 ft. 4 in. below	Brownish .	Sandy loam .	Granular .	3 ft. 4 in.-4 ft.	Brownish friable material
4	7 ft. below .	Yellowish .	Do. .	Do. .	7 ft.-8 ft. .	Yellowish material probably the decomposed material
		Samples taken	*from other places*			
	0-8 in. . .	Yellowish red	Sandy loam .	Granular .	...	
	Bed of R. Cossye	Blackish .	Clayey .	Slaty . .	...	Slate-like material found at the bed of the partially dried up R. Cossye
	45 ft. below .	Yellowish .	Clayey .	...	...	From the diggings of a well at Malida village Farm, between Lalgarh and Midnapur town

The local name for the laterite murrum at Midnapur is *kankar mati*. The loose or soft laterite murrum contains a considerable amount of plant food materials as indicated by the big trees growing on it. In some places it was noticed that the cultivators remove the top of the murrum layer and agriculture is practised on the yellowish clay at the bottom.

The red soils of the district of Bankura seem to be very similar in morphological features to those occurring in the adjacent district of Manbhum in Chota Nagpur. Rice is the main crop which is grown in Bankura ; sugarcane and *til* (*Sesamum indicum*) also do fairly well. Irrigation is necessary here during the dry periods.

(ii) *Northern Bengal : The red soil of the Barind tract*

The so-called Barind area is an extensive tract extending from the Godagari Ghat on the west up to the western bank of the Karotoya river. Rice grows very well in this area. At the Khetur Road the surface soil, locally known as *balka mati*, sets to a stiff mass in wet weather. On the other hand, the subsoil at Khetur Road, locally known as *lal mati* does not set to a stiff mass in wet weather. An interesting fact about the soil type at Bogra was that while red soil occurs on the western bank of the Karotoya river, on the eastern bank of the same river whitish alluvial soil occurs on which extensive cultivation of rice, jute and pulses is carried out. The Barind tract is similar in morphological features to the lateritic soils of Eastern Bengal.

TABLE IX

Soil profile No. P (D. U.) 49 Bog.

1. *Locality* : Sultanganj, Bogra, Bengal, western bank of Karotoya river. 2 furlongs S.-E. of Government Sericultural Farm
2. *Climate*—
   Temperature : Maximum 96°F. (in April) ; minimum 52°F. (in January)
   Rainfall (in.) : Jan. 0·38, Feb. 0·78, Mar. 1·24, April 2·27, May 8·50, June 14·03, July 13·06, Aug. 13·29, Sept. 11·67, Oct. 4·96, Nov. 0·74, Dec. 0·05 : Total 70·97
3. *Altitude* : 55 ft. a.s.l.
4. *Surface features* : Even
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Palm, date, banian, mango, mulberry and bamboo
   Cropping vegetation : Rice grown on the yellow subsoil below the red layer
6. *Soil-water conditions*—
   Free surface drainage
   Water-table : Maximum depth 25-30 ft. ; minimum depth 4-5 ft.
7. *Character of parent material* : Recent deposit

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft.	Brown	Clayey loam	Fine granular	0-1 ft.	Penetration of roots
2	1 ft.-2 ft.	Reddish brown	Loamy	Compact	1 ft.-2 ft.	Mixed with black iron concretionary material, increasing at greater depth
3	2 ft. below	Red	Loamy	Do.	2 ft.-4 ft.	Mixed with black iron concretionary material, increasing at greater depth, but more compact
4	12 ft.-25 ft. (app.)	Yellow.	Clayey	...	12 ft.-25 ft. (app.)	From the diggings of a well
5	25 ft.-30 ft. (app.)	Yellow	Sandy .	...	25 ft.-30 ft. (app.)	Do.
6	30 ft. below	Slaty black	Sandy .	...	30 ft. below	Do.

SOILS OF SOUTHERN INDIA

Profile samples were collected from Bangalore and from eastern, western and southern parts of Madras province. Soils of these parts of India mostly consist of red soils formed on Archean and metamorphic rocks and on coastal alluvium. Along the extreme part of the west coast in the Malabar district, laterite soils formed on low level laterites are found in abundance. Occasionally there are black soils of medium and light texture. The parent material of all these soil types are mostly granites.

TABLE X

Soil profile No. P (D. U.) 53 Bang.

1. *Locality* : Sankey's reservoir area, Bangalore city
2. *Climate*—
   Temperature : Maximum 93°F. (in April) ; minimum 57°F. (in January)
   Rainfall (in.) : Jan. 0·26, Feb. 0·17, Mar. 0·50, April 1·33, May 4·36, June 2·89, July 4·18, Aug. 5·38, Sept. 6·98, Oct. 5·90, Nov. 2·94, Dec. 0·48 : Total 35·37
3. *Altitude* : 3,000 ft. a.s.l.
4. *Surface features* : Undulating samples from a fissure mainly by gully erosion
5. *Nature of natural and cropping vegetation*—
   Natural vegetation : Mangoes, cashew nut, toddy palms
   Cropping vegetation : *Ragi*, horsegram and *juar*
6. *Soil-water conditions*—
   Free surface drainage
   Water-table : Maximum depth 20 ft.-30 ft. in winter ; minimum depth varies greatly
7. *Character of parent material* : Gneissic granites

Hori-zon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-3 ft. 6 in.	Red	Loamy	Granular	0-3 ft. 6 in.	
2	3 ft. 6 in.-4 ft. 6 in.	Red	Loamy	Do.	3 ft. 6 in.-4 ft. 6 in.	Mixed with white gravels
3	4 ft. 6 in.-6 ft.	Yellowish red	Loamy	Gravelly	4 ft. 6 in.-6 ft.	Mixed with numerous white gravels and more compact than layer '2'
4	6 ft.-7 ft.	Yellow	Sandy loam	Rocky	6 ft.-7 ft.	Compact rocky mass
5	Parent rock	...	...	...	...	

TABLE XI

Soil profile No. P (D. U.) 58 Can.

1. *Locality* : Talap village, about 1 1/4 mile from Cannanore station, Malabar district.

2. *Climate*—

Temperature : Maximum 90°F. (in May) ; minimum 70°F. (in January)

Rainfall (in.) : Jan. 0·25, Feb. 0·26, March 0·18, April 2·15, May 7·78, June 38·22, July 35·07, Aug. 18·83, Sept. 8·63, Oct. 7·95, Nov. 3·67, Dec. 0·61 : Total 123·60

3. *Altitude* : 50 ft. a.s.l.

4. *Surface features* : Undulating, profile taken from a quarry

5. *Nature of natural and cropping vegetation*—

Natural vegetation : Coconut, mango, jak

Cropping vegetation : Paddy, tapioca, *ragi* and pepper

6. *Soil-water conditions*—

Maximum depth of water-table 30 ft. in winter ; minimum depth of water-table 15-20 ft. in the rainy season

7. *Character of parent material* : Granites

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-6 in.	Greyish red	Gravelly loam	Gravelly	0-6 in.	
2	6 in.-5 ft. 5 in.	Red	Do.	Do.	6 in.-5 ft. 6 in.	Murrum, laterite, mixed with plenty of nodular iron concretionary pieces
3	Below 5 ft. 5 in.	Red mixed with yellowish white material	...	Rocky	5 ft. 6 in.-6 ft.	Honeycombed lateritic rock, yellowish material entrapped in the vesicles
4	Parent materials	...	...	...	...	

TABLE XII

Soil profile No. P (D. U.) 59 Pasu.

1. *Locality* : Pasumalai Farm area, Madura district

2. *Climate* —

Temperature : Maximum 100°F. (in May) ; minimum 69° F. (in January)

Rainfall (in.) : Jan. 0·60, Feb. 0·36, Mar. 0·51, April 2·03, May 2·89, June 1·37, July 1·92, Aug. 4·25, Sept. 5·11, Oct. 7·82, Nov. 4·95, Dec. 1·77 : Total 33·58

3. *Altitude* : 450 ft. a.s.l.

4. *Surface features* : Profile taken from a freshly dug pit at the foot of a small hill

5. *Nature of natural and cropping vegetation*—

Natural vegetation : *Babul* trees (*Acacia*), palms, coconuts and prickly pears

Cropping vegetation : Paddy, *juar*, cotton, groundnut, gingelly sesame

Horizon	Thickness	Description of each horizon			Sample depth	Remarks
		Colour	Texture	Structure		
1	0-1 ft. 2 in.	Brownish red	Sandy loam	Granular	0-1 ft. 2 in.	Mixed with pebbles
2	1 ft. 2 in.-4 ft. 3 in.	Red	Do.	Gravelly	1 ft. 2 in.-4 ft. 3 in.	Mixed with large quantities of pebbles and often nodular iron concretions
3	4 ft. 3 in.-8 ft. (app.)	Yellowish white	Sandy	Rocky	4 ft. 3 in.-6 ft.	Decomposed felspars, mostly cemented by iron concretions
4	8 ft.-40 ft. (app.)	Mixed black and white	...	...	8 ft.-40 ft. (app.)	Rocky sample taken from the diggings of a well. Decomposed felspars mixed occasionally with *kankars*, i.e. calcareous materials
5	40 ft. below (app.)	Parent material	...	...	...	

It appears on the whole that the soil types of the Madras province are similar to the soil types occurring in Assam. Regarding the nature of the red soils in Madras province, Leather [1898] has pointed out that generally in these soils the amount of lime is small or only moderate, magnesia is not high and phosphoric acid is uniformly low. On the other hand, the proportion of ferric oxide and alumina is usually high. Indeed their composition is in many respects similar to the lateritic soils, the chief feature of dissimilarity being in their respective proportions of phosphoric acid. Whilst the laterite soil contained very varying amounts of this valuable plant food, its proportion in these red soils were very uniform, the extreme variations being between 0·5 and 0·9 per cent.

A good deal of variations on the general nature and the distributions of the soils in the area were observed, there were distinct differences with respect to the depth of the soil and thus with distributions of soil inclusions, such as gypsums, calcium carbonate, quartz, etc.

The Malabar coast of the Madras province, like Bengal, is a part of India very rich in rainfall. Malabar is, therefore, a place of luxuriant tropical vegetation. The distribution of rainfall is fairly regular throughout the year. The dry season of the year does not last long enough to injure the vegetation and the amount of moisture accumulated in the soil during the rainy season is quite sufficient. A survey of the surface soils of the Malabar district has been made by Viswanath and Ramasubrahmanyan [1928].

DISCUSSION

It appears from what has been stated above that from the morphological point of view, the red soils studied can be divided into three broad types :—
(1) Red loams : characterized by argillaceous soil with a cloddy structure and the presence of only a few concretionary material, e.g. Purulia (Bihar), Palamau (Bihar), Mawphlang (Khasi hills, Assam), Uzanbazar (Gauhati, Assam), Tura (Garo hills, Assam), Bankura (Bengal), Khetur Road (Rajshahi, Bengal), Bangalore (South India), Jaydebpur (Bengal), Coimbatore (S. India), Vizagapatam (S. India).

2. Red earths : where the top soil is loose and friable but rich in concretions of a sesquioxide character, e.g. Ranchi (Bihar), Dhanmandal (Cuttack, Orissa), Nongpoh (Khasi hills, Assam), Bogra (Bengal), Pasumalai (Madura, S. India).

3. Laterite soils : where the surface is more akin to red earths, but with the presence of a definite layer of vesicular laterite rock below, e.g. Chybasa (Bihar), Kapileswar (Bhubaneswar, Orissa), Kapilas Road (Cuttack, Orissa), Khurda town (Puri, Orissa), Midnapur (Bengal), Tellichery (Malabar district), Cannanore (Malabar district).

Speaking generally, the profile characteristics of the red soils of Bengal seem to be of the same nature as those of Orissa. The soils of the Malabar coast are similar in morphological features to those occurring in Orissa and Midnapur. The profiles of loamy red soil of the southern parts of the Madras province seem to be similar in nature to those occurring in the province of Assam. The red soils of Bangalore appear to be mostly detrital laterites and, in general, their morphological features are similar to the ordinary red soils occurring in Coimbatore.

Nature of closely occurring red and black soils

The black cotton soil of Coimbatore occurs very close to a red soil area. The occurrence of such dissimilar red soils in close proximity has been discussed by many workers, but it appears that the most plausible explanation is that given by Marchand [1924] who discusses at length the question of the occurrence of dissimilar soils associated with similar rocks in South Africa. He points out that the texture of the soil ' will depend on the relative proportions of kaolin, silicic acid and ferric hydroxide, and these proportions are not the same for all rocks of similar mineralogical make up.' The presence of iron compounds in the rocks makes the resulting soil more open and easily drained. Moreover, sometimes an admixture of sandy material perhaps from an adjacent quartzite or sandstone takes place and the resulting soil is a red heavy loam. The mineralogical examination of these profiles has been undertaken. Mention may be made here of the work of Viswanath [1939] on the occurrence of red and black soils in close localities in the Madras province, including Coimbatore. He points out that the black soils have a much higher base-exchange capacity than the red soils. The silica-alumina ratio of the clay fractions are also higher. Compared to red soils, they are rich in calcium carbonate, possess a higher degree of colloidality, are more adhesive, expand greatly when wet and contract considerably when dry. These observations agree with those made by the author while working with two closely occurring types of red and black soils of South Africa [Raychaudhuri, 1936 ; Basu and Sirur, 1938]. (Cp. also the recently published work of Nagelschmidt, Desai and Muir [1940]).

Fox's view of Indian laterite and lateritic soils

Discussing the nature of laterite and lateritic soils occurring in India, Fox [1936] has suggested that while the term ' laterite ' can be used in a comprehensive sense, the more finished product should be precisely termed ' laterite ', whilst the red soils of the Malabar coast which Buchanan originally designated as ' laterite ' must in the main be regarded as lithomargic laterite, meaning thereby a comparatively unfinished product. The problem on the nature of Indian laterites and lateritic soils has been summarized and discussed by Raychaudhuri [1937], and a detailed examination of the physico-chemical properties of the profile samples has been undertaken with a view to finding out the nature of these soil types, especially in the light of the views expressed by Fox.

Honeycombed laterite rocky mass

Discussing the occurrence of the honeycombed masses, Sen [1939] has expressed the view 'that in India a soil may be termed laterite when a morphological examination reveals these profile characteristics, especially in the presence of cellular concretions of iron irrespective of the soil's chemical composition'. Thus Sen has suggested that in the study of laterite soils the soil chemist or the pedologist should confine his attention to the surface soil, leaving the study of the underlying honeycombed mass to the geologist. On the whole it appears that the separation of the iron oxide in the form of nodules and the gradual cementation of the latter to form a consolidated honeycombed mass is one of the characteristic features of this type of soil formation. The so-called 'murrum laterite' may thus be an intermediate stage in the formation of 'rock laterite'. There appears to be no general relationship of the formation of the iron crust with the ground water level or with the annual rainfall except that the iron crust should have formed under alternate conditions of desiccation and saturation.

SUMMARY

The morphological features of some profiles of red soils from Chota Nagpur, Orissa, Assam, Bengal, and South India have been examined. The nature of these soil types has been discussed.

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REFERENCES

Basu, J. K. and Sirur, S. S. (1938). *Ind. J. Agric. Sci.* **8**, 637-97
Fox, C. S. (1936). *Rec. Geol. Surv. Ind.*, Pt. IV, 389
Hooker, J. D. (1854). *Himalayan J.* (Abridged edn.), p. 490; Ward, Lock & Co., Ltd., London
Leather, J. W. (1898). *Agric. Ledger* No. **2**, 32
Marchand, de C. (1924). *S. African J. Sci.* **21**, 162-81
Nagelschmidt, G.; Desai, A. D. and Muir, Alex. (1940). *J. Agric. Sci.* **30**, 639
Oldham, R. D. (1893). *Geology of India*
Raychaudhuri, S. P. (1936). Ph.D. Thesis, University of London
———————— (1937). *Sci. and Culture,* **3**, 69-74
Schokalsky, Z. J. (1932). *Contributions to the knowledge of the soils of Asia,* **2**, 53-155
Sen, A. T. (1939). *Ind. Soc. Soil Sci. Bull.* No. **2**, 11
Viswanath, B. (1939). *Ind. Soc. Soil Sci. Bull.* No. **2**, 4
———————— and Ramasubrahmanyan, T. S. (1928). *Dept. Agric., Madras, Bull.* No. **19**

STUDIES ON INDIAN RED SOILS

IV. NATURE OF THE WEATHERING COMPLEX AS DETERMINED BY THE VAN BEMMELEN-HISSINK METHOD OF HYDROCHLORIC ACID EXTRACT

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VAN BEMMELEN [1877, 1879, 1888, 1904] studied the soil silicates in detail and showed that they can be divided into two groups :—

(1) The unweathered portion which occurs even as crystals in clays and to which definite chemical formulae can be assigned, and

(2) The weathered portion which he considered to be absorption complex of the form SiO_2, pAl_2O_3, qFe_2O_3, rCaO, etc. and not definite minerals or compounds to which definite chemical formulae can be assigned.

He divided this latter group into two classes*:

(*a*) Those completely decomposed by boiling hydrochloric acid (Silicate A), and

(*b*) Those resistant to this treatment but decomposed by hot concentrated sulphuric acid (Silicate B).

Van Bemmelen established the fact that the bases held in silicate B are not on the whole exchangeable and that silicate A displays colloidal properties in a more marked degree than silicate B. The work of Van Bemmelen suggests that silicate A is the reactive body present in the soil. As Russell [1937] has pointed out, however, this distinction between silicate A and B is not sharp. Thus it is to be pointed out that hydrochloric acid decomposes appreciable quantities of many parent rocks, e.g. basalt, often some silicate B, though not as vigorously as sulphuric acid, and it does not decompose all the material possessing base-exchange capacity in the soil. Hydrochloric acid extract has, however, been often used by workers all over the world in order to find out the nature of the so-called weathering complex.

Sigmond [1938] has pointed out that the silicic acid liberated from the silicates by the actoin of hydrochloric acid. although insoluble in that acid, nevertheless forms an integral part of the hydrochloric acid extract. The silicic acid should be therefore dissolved in potassium hydroxide or sodium hydroxide and added to the SiO_2 soluble in hydrochloric acid.

In the course of the work at the Dacca University on the nature of the lateritic and red soils of India, it was felt desirable to examine the nature of the active part of the weathering complex as defined by Van Bemmelen (Van Bemmelen's silicate A). Determinations of the percentages of the different constituents of soils that are dissolved by boiling hydrochloric acid and of the alkali-soluble silica in the residue after extraction with hydrochloric acid were accordingly undertaken.

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* Harrasowitz [Sigmond, 1938] applies the term ' allophane ' to materials of group (*a*) and kaolin to materials of goup (*b*).

Experimental

Procedure for the determination of silica, alumina and iron oxide

The analyses of the percentages of constituents of soils dissolved by boiling concentrated hydrochloric acid were carried out by following essentially Van Bemmelen-Sigmond's method as modified by A. E. A. [1931]. 25 gm. of soil (2-mm. sieve) treated with 250 c.c. of concentrated hydrochloric acid (sp. gr. 1·16) in 600-c.c. tall beaker, covered with a clock glass, were boiled gently for one hour, cooled, filtered and the residue lixiviated with hot water till it was free from acid. This filtrate (filtrate A) was made up to 500 c.c. From this 100 c.c. aliquot was taken in a casserole, evaporated in a water-bath after addition of a few c.c. of strong HNO_3. When evaporation was complete, a few c.c. of strong HCl were added. After this, when evaporation was complete, the dried residue was heated for about six hours at about 120°C. to dehydrate the silica and then the mass was dissolved with gentle stirring, by means of dilute hydrochloric acid (approximately 2*N*), filtered through a gravimetric filter paper and washed till free from chloride. The filtrate (filtrate B) was made up to 250 c.c. The filter paper with the residue was ignited for the determination of SiO_2, whilst alumina and iron oxide were determined in filtrate B.

Determination of the alkali-soluble silica

In the residue after hydrochloric acid extraction, the alkali-soluble silica was determined by following essentially the method devised by Sigmond [1928]. The insoluble residue after hydrochloric acid extraction was dried on a water-bath. The filter paper was ignited and added to the insoluble residue. By this process, colloidal silica became insoluble in dilute alkali. To avoid this care was taken so that only a small quantity of the insoluble residue from the decantation reached the filter paper. To dissolve the soluble silica. 250 c.c. of potassium hydroxide solution of sp. gr. 1·04 was added and gently heated at 55°C. for five minutes in an Erlenmeyer flask and lixiviation with water was continued until there was no alkaline reaction. Silica was then determined from the solution. The results of analyses of some typical profiles of red soils collected fron various parts of India are given in Table I.

Table I

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/Fe_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	Fe_2O_3			
Bengal—Dacca Farm .	0-6 in. . .	5·03	0·112	5·142	12·96	6·96	0·669	0·499	2·917
	6 in.-2 ft. 3 in. .	10·81	0·050	10·860	5·90	6·75	3·106	1·797	1·345
	2 ft. 3 in.-4 ft. .	12·13	0·125	12·255	9·81	9·23	2·108	1·317	1·665
Suri, Birbhum .	0-1 ft. . .	5·24	0·034	5·274	2·72	2·44	3·271	2·080	1·746
	1 ft.-1 ft. 6 in. .	8·00	0·023	8·023	6·35	4·60	2·563	1·644	1·799
	* Below 13 ft. .	(K) 15·62	0·164	15·784	5·14	8·97	5·178	2·449	0·901
	** Below 13 ft..	(K) 7·81	0·091	7·901	2·73	3·92	4·882	2·546	1·091

* This is a yellow clay from a well at depth below 13 ft. (very near from where the other two samples were collected).

** This is a yellowish white clay from a well at depth below 13 ft. This was heaped by the side of the well and grass was growing on it. The sample was taken from the heap 1 in.-5 in. after removing the top 1 in. to get rid of grass roots, etc.

TABLE I—*contd.*

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/F_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	F_2O_3			
Bengal (Barind tract)—									
Bogra .	0-1 ft. . .	4·62	Very slight	4·62	0·88	2·11	8·855	3·500	6·533
	1 ft.-2 ft. .	6·06	0·061	6·121	3·02	1·08	3·436	2·798	4·385
	2 ft.-4 ft. .	12·26	0·082	12·342	5·85	2·52	3·575	2·804	2·297
	* 12 ft.-15 ft. .	8·37	0·083	8·453	2·39	4·99	6·589	2·674	0·685
	** 25 ft.-30 ft. .	8·51	1·462	9·972	3·99	4·39	4·236	2·490	1·425
Khetur Road, Rajshahi	0-1 ft. 10 in. .	11·05	0·161	11·211	2·72	2·26	6·983	4·562	1·888
	1 ft. 10 in.-2 ft. 3 in.	14·95	0·069	15·019	6·89	5·46	3·695	1·630	1·979
	2 ft. 3 in.-4 ft. .	15·69	0·054	15·744	6·79	5·26	3·928	2·629	2·071
Hyderabad—									
Bidar . .	0-1 ft. . .	34·29	0·055	34·345	10·14	28·56	3·042	1·582	1·063
	1 ft.-3 ft.. .	28·36	0·043	28·403	18·49	13·46	2·603	1·797	2·283
	3 ft.-4 ft.. .	20·62	0·211	20·831	24·14	18·20	1·462	0·997	2·144
Himayeth sagar	0-3 in. .	6·49	0·067	6·557	5·99	3·32	1·856	1·381	2·917
	3 in.-1 ft. 6 in. .	16·53	0·039	16·569	5·50	1·55	5·105	4·347	5·724
	† 1 ft. 6 in.-4 ft.	11·40	0·104	11·504	2·51	7·86	7·764	2·644	0·516
	†† 1 ft. 6 in.-4 ft.	17·73	0·067	17·797	6·97	7·74	4·328	2·670	1·455
Hyderabad—									
Alisagar . .	0-1 ft. . .	1·62	0·065	1·685	2·90	8·20	1·054	0·384	0·571
	‡ 1 ft. downwards	12·86	0·110	12·970	10·70	8·60	2·049	1·368	2·011
Central Provinces—									
Telankheri, Nagpur	‡‡ 0-2 in. .	21·06	1·072	27·132	35·41	8·02	1·299	1·140	7·137
	‡‡ 2 in.-2 ft. 6 in.	37·19	0·004	37·194	35·21	7·73	1·790	1·576	7·362
	‡‡‡ 13 ft.-16 ft.	49·02	0·072	49·092	9·96	9·66	8·352	5·219	1·666
	‡‡‡‡ 16 ft.-21 ft.	44·96	0·113	45·073	19·54	6·53	3·909	3·241	4·826

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* This is the approximate depth, taken from the digging of a well very near to the place from where the other three samples were collected.

** This is the next layer of the soil marked with * from the digging of the same well.

†† This is a whitish material occurring occasionally in the same horizon of the soil as is marked with †. Said to be due to the decomposition of pigmatite.

‡ This is the second horizon of the soil usually extending 5 to 6 ft. below the surface.

‡‡‡ Decomposed rock from the side of a hill cuttings about 50 yards away from the hill on which the sample marked with ‡‡ have been collected.

‡‡‡‡ Greenish grey layer of probably more than 5 ft. in depth underlying the sample marked with ‡‡‡

TABLE I—*contd.*

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3/Fe_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	Fe_2O_3			
Central Provinces—									
Chandkhuri Farm, Raipur	0-4 in.	4·49	0·208	4·695	23·04	21·35	0·346	0·220	1·745
	4 in.-1 ft. 5 in.	9·25	0·265	0·515	24·35	22·05	0·663	0·425	1·784
	1 ft. 5 in.-4 ft.	5·83	0·049	5·879	32·04	24·57	0·311	0·214	2·107
Labhandi	* 0-8 in.	5·67	0·081	5·751	16·25	8·76	0·600	0·450	2·998
	**8 ft.-10 ft.	4·32	0·065	4·385	15·77	5·31	0·472	0·390	4·808
Bihar (Chota Nagpur)—									
Putida, Chybasa	0-1 ft.	35·39	0·091	35·681	7·22	6·54	8·374	5·367	1·787
	1 ft.-2 ft. 9 in.	39·89	0·042	39·932	11·32	7·19	8·375	5·368	1·805
Assam—									
Uzanbazar, Gauhati	0-6 in.	12·84	0·112	12·952	5·46	7·16	4·021	2·219	1·232
	6 in.-11 ft.	13·09	0·113	13·203	4·70	10·82	4·766	1·965	0·702
	11 ft.-16 ft.	14·75	0·068	14·818	12·79	7·24	1·965	1·455	2·852
	†† Below 16 ft.	14·89	0·102	14·992	5·37	2·87	4·734	3·559	3·029
Tura, Garo hills	0-3 in.	11·26	0·102	11·362	7·84	19·47	2·459	0·969	0·651
	3 in.-1 ft. 8 in.	10·68	0·092	10·772	8·99	9·99	2·032	1·204	1·453
	1 ft. 8 in.-2 ft. 8 in.	11·32	0·093	11·413	6·61	15·61	2·926	1·189	0·685
	2 ft. 8 in.-4 ft.	7·78	0·101	7·881	4·06	3·99	3·294	2·048	1·645
Assam—									
Nongpoh, Khasi and Jaintia hills	0-6 in.	2·44	0·081	2·521	5·73	7·67	0·746	0·408	1·208
	6 in.-3 ft. 6 in.	15·22	0·089	15·309	11·12	7·60	2·344	1·641	2·365
	3 ft. 6 in.-4 ft. 2 in.	15·09	0·087	15·177	12·15	8·41	2·117	1·485	2·335
	4 ft. 2 in.-6 ft.	14·18	0·012	14·192	13·66	9·92	1·760	0·633	2·228
Madras (Malabar coast)—									
Kakat, Cannanore	0-1 ft. 3 in.	7·82	0·116	7·936	15·45	13·18	0·871	0·570	1·895
	1 ft. 3 in.-4 ft.	9·77	0·142	9·912	13·46	25·01	1·248	0·581	0·870
Puzathi, Cannanore	16 ft.-30 ft.	5·29	0·276	5·566	8·33	8·21	1·334	0·732	1·641
	‡ Below 30 ft.	6·99	0·276	7·266	2·98	3·02	4·134	2·515	1·561
	‡‡ Below 30 ft.	7·02	0·068	7·088	3·89	3·66	3·088	1·952	1·718

** This is a yellowish white clay occurring further down the darkish clay which occurs just below the soil marked with*

†† This layer extends up to the parent material.

‡‡ White substance, often with fossilized roots occurring as lumps and layers in and between the same layer as marked with ‡ and the layer above that.

TABLE I—*contd.*

Analytical results of some typical profiles of red soils

Locality	Depth	SiO_2 per cent			Sesquioxides in HCl extract (per cent)		SiO_2/Al_2O_3 (molecular)	SiO_2/R_2O_3 (molecular)	Al_2O_3 F_2O_3 (molecular)
		Alkali-soluble	Acid-soluble	Total soluble	Al_2O_3	Fe_2O_3			
Madras (Nilgiri hills)—									
3,000 ft. a.s.l.	0-1 ft. 8 in.	34·43	0·128	34·558	8·60	11·42	6·811	3·740	1·217
	1 ft. 8 in.-3 ft.	36·67	0·079	36·749	14·63	7·62	4·260	3·221	3·101
	Below 3 ft. (to a condiserable depth)	30·21	0·038	30·248	9·06	10·73	5·659	3·266	1·365
5,000 ft. a.s.l.	0-1 ft.	7·82	0·370	8·190	13·73	10·67	1·001	0·683	2·080
	1 ft.-2 ft.	17·87	0·345	18·215	10·01	8·52	3·085	2·022	1·900
	2 ft.-6 ft.	36·51	0·017	36·527	2·68	5·00	23·11	10·72	0·866
7,000 ft. a. s. l.	0-1 ft.	6·27	0·367	6·637	14·79	22·53	0·762	0·392	1·058
	1 ft.-3 ft.	14·12	0·036	14·156	29·56	22·69	0·812	0·549	2·105
	3 ft.-4 ft. 6 in.	5·33	0·912	6·242	30·01	24·36	0·353	0·235	1·991
	4 ft.-6 in.-6 ft.	4·67	0·032	4·702	34·09	11·57	0·234	0·193	4·785
Madras—									
Stambhalaguruva, Guntur	0-8 in.	59·87	0·046	59·916	6·46	2·09	15·72	13·1	5·008
	8 in.-1 ft. 2 in.	51·00	0·057	51·057	12·53	4·78	6·907	5·59	3·366
	1 ft. 2 in.-5 ft.	52·06	0·062	52·122	14·09	5·32	6·270	5·09	3·400
Govt. Fruit Farm, Cape Comorin	0-2 ft.	9·55	0·446	9·996	11·51	1·60	1·478	1·36	11·58
	2 ft.-3 ft.	8·78	0·143	8·923	7·83	5·13	1·931	1·38	2·468

DISCUSSION

The data in the above table indicate the manner in which the percentages of Al_2O_3 and Fe_2O_3 have been washed down the profile. It will also be seen that the value SiO_2/R_2O_3 of the HCl extract of the profile samples from the following places are considerably low, e.g. Nilgiri hills (3), (7,000 ft. a.s.l.), Kakat (Cannanore, Malabar), Chandkhuri Farm (Raipur, C. P.), Labhandi (C. P.). On the other hand, the SiO_2/R_2O_3 ratios of the HCl extracts are comparatively very high in the following cases, Putida (Chybasa, Bihar), Nilgiri hills (1) (3,000 ft. a.s.l.), Stambhalaguruva (Guntur, Madras). In the case of soil samples from Nilgiri hills, the greater the height of the place from where the sample has been taken, the lower generally is the SiO_2/R_2O_3 ratio.

There is a maximum value for SiO_2/Al_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3, at an intermediate depth in the case of the profile samples from Nongpoh (Khasi and Jaintia hills) and Nilgiri hills (3), whilst with the profile from

Dacca Farm (Bengal), the value Al_2O_3/Fe_2O_3 has got a minimum at an intermediate depth, but on the other hand, in the case of the profile samples from Chandkhuri Farm (Raipur, C. P.), the value Al_2O_3/Fe_2O_3 gradually increases down the profile. Profile samples from Suri (Birbhum, Bengal), Nilgiri hills (1) (3,000 ft. a.s.l.) and Rajshahi (Bengal) show a minimum value for SiO_2/Al_2O_3 and SiO_2/R_2O_3 at an intermediate depth. The value Al_2O_3/Fe_2O_3 attains a maximum at an intermediate depth in the case of profiles from Suri (Birbhum, Bengal), and Nilgiri hills (1) (3,000 ft. a.s.l) and on the other hand Al_2O_3/Fe_2O_3 increases down the profile in the case of the profile from Rajshahi (Bengal). The profile samples from Nilgiri hills (2) show a gradual tendency for the value of Al_2O_3/Fe_2O_3 to decrease down the profile, whilst the values SiO_2/Al_2O_3 and SiO_2/R_2O_3 increase down the profile.

All the profile samples from Assam seem to contain considerable amount of unweathered materials. This is evident from the comparatively small amounts of the total quantity of materials which are dissolved by boiling hydrochloric acid and subsequently by potassium hydroxide. All the red soils of Assam appear, therefore, to be immature and may conveniently be classed, with a few exceptions, as red loams. It may also be suggested from the above data that in the case of soil samples from Nilgiri hills occurring at 7,000 ft. a. s. l., Bidar (Hyderabad), Telankheri (Nagpur, C. P.), Putida (Chybasa, Chota Nagpur), Nilgiri hills (1) (3,000 ft. a.s.l.) and Stambhalaguruva (Guntur, Madras) contain considerable proportions of alkali-soluble silica, and it may be called lithomargic laterite in the sense the term has been used by Fox [1936].

SUMMARY

1. The percentages of silica, alumina and iron oxide dissolved from the soil by treatment with boiling hydrochloric acid and the percentages of alkali-soluble silica in the residue after extraction with hydrochloric acid have been determined.

2. Soils occurring at a height of 7,000 ft. a.s.l. in the Nilgiri hills are considerabley rich in the acid-soluble oxides of aluminium and iron. So also are the samples from Bidar (Hyderabad). Telankheri (Nagpur, C. P.), Chandkhuri Farm (Raipur, C. P.), and from Kakat (Malabar Coast).

3. The percentages of alkali-soluble silica do not show any regularity down the profiles. In the case of soils from Nilgiri hills, it is found that the greater the height from where the soils were collected the less is the quantity of alkali-soluble silica.

4. The red soils of Assam appear to be of the class of red loam, and the soils from the Barind tract are similar in nature to the soils of Assam.

5. The trends of variation of molecular ratios SiO_2/Al_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3 of HCl extract of profile samples have been brought about.

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REFERENCES

A. E. A. (1931). *Agric. Progress* **81,** 134

Fox, C. S. (1936). *Rec. Geol. Survey of India,* Part IV, 390

Russell, E. J. (1937). *Soil conditions and plant growth* : London

Sigmond, A. A. J. De (1928). *Trans. 1st Internat. Cong. Soil Sci.* **1,** 60

———————— (1938). *Principles of soil science.* Eng. Ed.

Van Bemmelen, J. M. *et. al.* (1877). *Landw. Versuch. Stat.* **21,** 135

————————(1879). *Landw. Versuch. Stat.* **23,** 265

————————(1888). *Landw. Versuch. Stat.* **35,** 69

————————(1904). *Zeitsch. Anorg. Chem.* **42,** 265

STUDIES ON THE FIXATION OF PHOSPHATES IN INDIAN RED SOILS

I. APPLICABILITY OF TRUOG'S METHOD FOR THE DETERMINATION OF AVAILABLE PHOSPHATES

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(With two text-figures)

IT is well known that tropical soils, such as those found in India, are usually rich in iron and often in titanium, and therefore, wherever any dose of phosphate is applied to such soils the phosphate is fixed by the soil in difficultly soluble forms. The study of the nutrient status of Indian soils, especially with reference to phosphate, is therefore an important one. Before any systematic study on the fixation of phosphates is undertaken, it is obviously desirable to examine the applicability of the important existing methods for the determination of available phosphates in the case of Indian soils.

The classical researches of Dyer [1894] to find out the *p*H of the juice of the root sap of various plants led to the development of the citric acid method for the determination of available plant nutrients, like phosphorus and potassium. Since that time a number of methods have been proposed by different workers, depending on various factors and principles. Most of these methods depend on the use of one or the other inorganic or organic acid of a particular strength as solvent for extracting the soil phosphates. Malherbe and Myburgh [1935] have compared almost all existing methods for the determination of available phosphates with South African soils. They have come to the conclusion that chemical methods are in general speedier and less expensive than Neubaur's seedling method. They have compared the applicability of the chemical methods with non-calcareous soils. In the case of calcareous soils, however, the objection raised by Das [1926] to the use of Dyer's citric acid method cannot be set aside easily. Of all the chemical methods which are in use, the one devised by Truog [1930] appears to be the most convenient and rapid. The present paper records some data on available phosphates which are obtained with some Indian red soils by Truog's method, and these data have been compared with those obtained by the acetic acid method [Williams, 1928] and also by Dyer's method [1894].

EXPERIMENTAL PROCEDURE

Determination of available phosphate by Truog's method

One gm. soil and 200 c.c. of $N/500$ sulphuric acid solution buffered to *p*H 3·0 by adding 3 gm. of ammonium sulphate per litre were shaken in a mechanical shaker for ½ hour. This was filtered through a Whatman No. 2 filter paper, first few c.c. being discarded. To an aliquot of this 2 c.c. of ammonium molybdate-sulphuric acid solution (prepared according to Truog and Meyer [1929]) and six drops of stannous chloride solution (prepared according to Troug and Meyer [1929]) were added and the mixture made up to 100 c.c. The colour which was developed was compared with a standard within a few minutes.

Determination of available phosphate by acetic acid method

12·5 gm. of soil were placed in a beaker with 100 c.c. *N*/2 acetic acid and the mixture was stirred. After stirring several times and allowing to stand for at least two hours the supernatant liquid was poured into a filter, the filtrate being collected in a 500-c.c. measuring flask. The soil was then leached with the same acetic acid solution 30-40 c.c. at a time, until 500 c.c. were collected. To an aliquot of this, 4 c.c. ammonium molybdate-sulphuric acid solution and six drops of stannous chloride solution were added and made up to 100 c.c. The colour which developed was compared against a standard within a few minutes.

Determination of available phosphate according to Dyer's method

A weight of air-dry soil corresponding to 100 gm. of dry soil were placed in a one-litre stoppered bottle with one litre distilled water and 10 gm. of citric acid (recrystallized). The soil was allowed to remain in contact with this one per cent citric acid solution for seven days, the bottle was shaken several times each day except the last, when most of the soil settled down. After seven days the solution was filtered and 75 c.c. of the filtrate were taken in a 300-c.c. Kjeldahl flask to which 10 c.c. of concentrated hydrochloric acid were added, followed by 12 c.c. of 20 per cent sodium permanganate solution. The sides of the flasks were washed down with a little water. After standing half an hour, the contents were vigourously digested till no manganese precipitate remained. The contents were transferred to a 100-c.c. measuring flask and 4 c.c. of 10 per cent potassium ferrocyanide solution were added drop by drop with frequent shaking. Several minutes later the mixtures were titrated with ammonia until the blue colour just turned purple. 1·5 c.c. of 2 *N* sulphuric acid were then added and made up to the mark with water. The solution was then filtered and after discarding the first few c.c. an aliquot was taken to which 4 c.c. of ammonium molybdate-sulphuric acid solution and six drops of stannous chloride solution were added and made up to 100 c.c. and the colour was compared against a standard within a few minutes.

EXPERIMENTAL RESULTS AND DISCUSSION

Twelve Indian red soils as described in Table I were selected. The available phosphates of these soils were determined by the three methods. The results are given in Table I.

TABLE I

Amount of phosphorus coming into solution by different methods

Locality	Depth (in.)	p. p. m. of P coming into solution by		
		Truog's method	Dyer's method	Acetic acid method
Institute area, Dacca Farm, Dacca	0—6	12	7	1·7
	6—27	17	9	2·8
Himayetnagar, Hyderabad . .	18—48	7	5	1·3
Chandkhuri Farm, Raipur, C. P.	0—4	12	6	1·5
	4—17	9	6	1·4
	17—48	11	5	1·4
Puzathi, Cannanore, Malabar .	192—360	7	4	1·1
	below 360	7	3	1·6
Nilgiri hills, 3,000 ft. a. s. l. . .	B-horizon	9	6	1·3
Nilgiri hills, 7,000 ft. a. s. l. .	12—36	14	7	2·3
	36—54	13	6	2·0
	54—72 (app.)	13	8	2·1

Fig. 1 shows graphically the relationship between the data on available phosphates of the soils by the three different methods. It will be seen that there is a fairly good degree of correlation (r between Truog's method and Dyer's method = 0·866, r between Truog's method and acetic acid method =0·885, r between Dyer's and acetic acid method =0·762) between the data obtained by any two methods. It will also be seen from Table I that the amount of phosphorus coming into solution in Truog's method is almost double of that obtained by Dyer's method. This is in agreement with the observations made by Malherbe and Myburgh [1935].

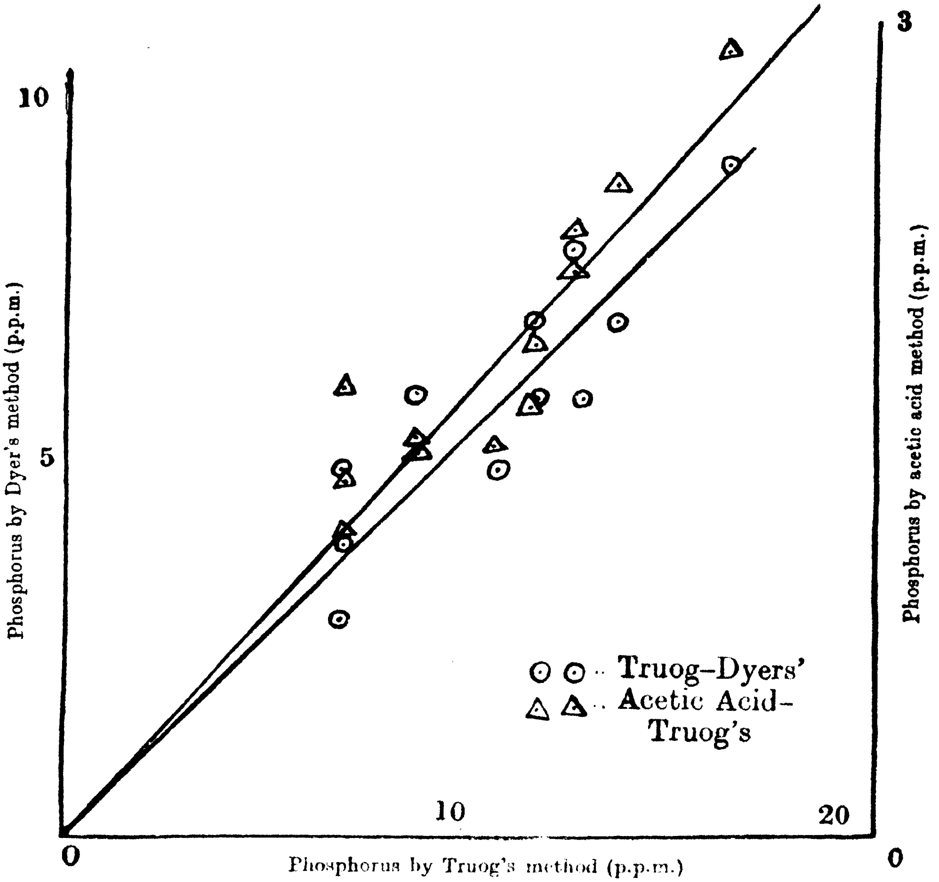

Fig. 1. Relation between the amounts of phosphorus coming into solution by Truog's method with that by Dyer's method and by acetic acid method with that by Truog's method (in case of Indian red soils)

The applicabilities of the acetic acid method and the Truog's method have also been compared with a few other non-calcareous soils of India, most of them having been collected from unmanured paddy fields. The results are given in Table II.

The last column of Table II shows the ratio of the data obtained by Truog's method and by the acetic acid method. A fair degree of correlation (r between Truog's method and the acetic acid method $=0 \cdot 992$) exists between the two sets of data and is also shown graphically in Fig. 2.

CONCLUSION

It follows from what has been stated above that Troug's method is equally applicable to Indian red soils. In addition it has got some advantage over other methods, namely that comparatively much less time is required for the estimation of the phosphate by Truog's method. Also, the extracting medium being a buffered solution, the pH of the soil suspension remains fairly constant.

TABLE II

Amount of phosphorus coming into solution by acetic acid method and by Truog's method

Locality	p. p. m. of P coming into solution By Truog's method (T)	 By acetic acid method (A)	 Ratio T/A
Coimbatore 15	45	6·2	7·3
Coimbatore 3	48	6·3	7·6
Coimbatore 1	37	6·1	6·1
Gaya	46	7·0	6·6
Kanke	31	4·7	6·8
Sabour N	25	3·6	6·8
Titabari I	27	3·7	7·3
*Dacca I	311	48	6·5
*Dacca II	498	63	7·9
Kanwya	13	1·9	7·0

*These soils were taken from a flower garden which was heavily treated with phosphatic manures

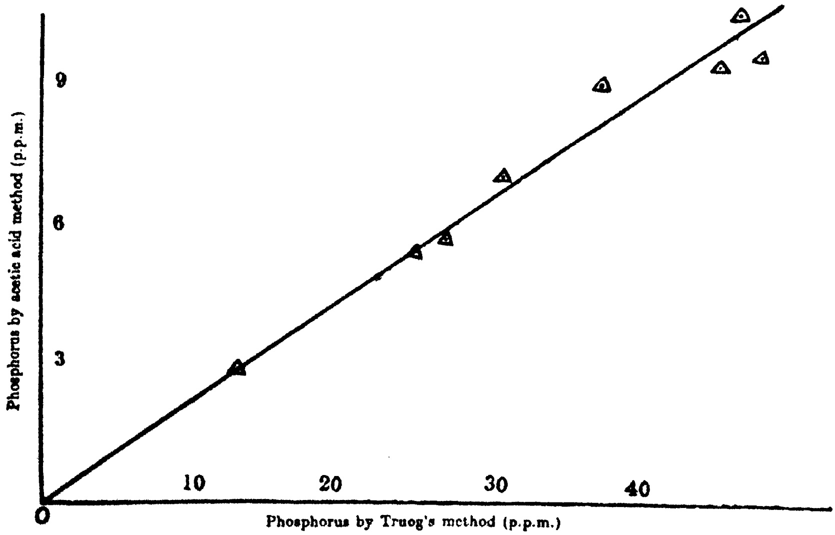

FIG 2. Relation between the amount of phosphorus coming into solution by acetic acid method and by Truog's method (in case of some rice soils)

Moreover, the amount of phosphorus (available) obtained by Truog's method is higher than that obtained by either of the other two methods, and hence Truog's method can comparatively more easily differentiate the fertilities as related to phosphate status of any two soils.

SUMMARY

The applicability of Truog's method for the determination of available phosphates in the case of Indian red soils has been tested. It is found that as far as the Indian red soils are concerned, Truog's method for the determination of available phosphorus can easily be used, because the data obtained by Truog's method bear fair correlation to those obtained by the other two widely used methods, namely Dyer's method and the acetic acid method.

Advantages of Truog's method over the other two methods have also been pointed out.

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REFERENCES

Das, S. L. (1926). *Mem. Dept. Agric. Ind.* (*Chem. Ser.*) **8**, No. 6

Dyer, B. (1894). *Trans. Chem. Soc.* **65**, 115

Malherbe, I. De V. and Myburgh, S. J. (1935). *Trans. Third Internat. Cong. Soil. Sci.* **1**, 238

Truog, E. (1930). *J. Amer. Soc. Agron.* **22**, 874

Truog, E. and Meyer, A. H. (1929). *Ind. Eng. Chem.* (*Anal. Ed.*) **1**, 136

Williams, R. (1928). *J. Agric. Sci.* **28**, 439

DETERMINATION OF RESISTANCE TO THE BLIGHT DISEASE [*MYCOSPHAERELLA RABIEI* KOVACEVSKI=*ASCOCHYTA RABIEI* (PASS.) LAB.] IN GRAM TYPES

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I. Introductory

As the result of the investigations already reported [Luthra and Bedi, 1932; Sattar, 1933; Luthra, Sattar and Bedi, 1935] the following measures were devised and recommended to farmers for the control of the blight disease of gram [*Mycosphaerella rabiei* Kovacevski=*Ascochyta rabiei* (Pass) Lab.], which is now prevalent in all the gram-growing districts of the Punjab and causes a damage of about three to four crores of rupees (£ 2.25 to £ 3 millions) annually :—

1. The sowing of disease-free seed supplied by the Agricultural Department.
2. Elimination of diseased gram material from fields by—
   - (*a*) harvesting the entire crop by uprooting by hand and thus leaving fields free of infection.
   - (*b*) ploughing the fields with a furrow-turning plough after the first shower of rain in summer to bury the remnants of diseased plants.
   - (*c*) sweeping the threshing floors and burying or burning the collected debris.

These methods were enforced by the Agricultural Department and Revenue staff in the Attock tehsil. They stood the test for three years and proved effective against the disease. But generally they are not executed to a level of perfection collectively by all the farmers over the entire area in the affected locality. Therefore, when favourable conditions for the spread of the blight disease, i.e. low summer rainfall and high winter rainfall with many rainy days uniformly distributed, prevail, there is a widespread infection of the disease. Consequently the selection of blight-resistant gram types has been considered a surer and more dependable means of combating the disease. This point has been kept in view ever since the investigation of this serious disease was started. The work on the production of resistant types was facilitated by the findings already published by the authors [Luthra, Sattar and Bedi, 1939] to the effect that the causal fungs of gram blight (*Ascochyta rabiei*) in the Punjab has no physiologic forms.

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* All the three authors are jointly responsible for the work.

II. EXPERIMENTAL

A. MATERIAL AND METHODS

Three hundred and ninety-two gram types (named types and miscellaneous collections) were obtained from various localities in India and foreign countries and their relative resistance to *Mycosphaerella rabiei* was tested. In the first instance, inoculation tests on 187 collections which were obtained by the authors directly were carried out in 1933-34, 1934-35 and 1935-36. As a result of these tests, it was observed that three types showed marked resistance. Attention was concentrated on the study of performance of these types, and inoculation experiments were continued on them. Two hundred and five samples which were supplied to the authors by the Millet Botanist, Sirsa (Punjab), were tested during 1937-38 and 1938-39. The particulars of all the collections are given in the text. The various samples were grown at the Agricultural Farm, Campbellpur, where the blight disease has been appearing in succession for several decades. About 200 plants of each sample were grown every year for the inoculation tests during the first three years. Afterwards inoculations on a larger scale (on about 5,000 plants of each selected type) were carried out. In certain experiments, the plants were grown in small plots enclosed by *sarkanda* (*Saccharum spontaneum*) screens to protect them from outside infection.

Equal numbers of plants from each sample were subjected to the following two methods of inoculation :—

(1) By spraying with a pycnospore suspension in water. Spores were taken from the fungus *M. rabiei* grown in pure cultures on oat-meal agar for three weeks. The plants were kept covered by *sarkanda* for about a week to provide moist conditions for the development of the disease. The inoculations were done in February each year, and, in order to provide heavy infection, the inoculations were repeated in March again.

(2) By spreading over the plants blighted gram plant debris chopped into small pieces, after ensuring that the stalks of the debris carried plenty of pycnidia of *M. rabiei* and that more than 70 per cent of the pyconspores contained in them were viable. The plants inoculated by this method were not covered with *sarkanda*. In this case infection occurred after rain even if it was received months after inoculation. (Previous tests had shown that the fungus carried on debris remains active for three years).

Both the methods were equally successful . Other methods of inoculation are described in their appropriate places in the text.

B. RELATIVE RESISTANCE OF THE VARIOUS TYPES AND COLLECTIONS

The results of inoculation experiments on the various types and collections of gram are summarized in Table I.

The results show that all the Indian types are highly susceptible to the disease and that out of the foreign types Pois Chiches No. 4732, No. 199, and No. 281 are very resistant. The others are either very susceptible or not so resistant as to be suitable for conditions in the northern Punjab, which are often very favourable for the development of the disease.

The three resistant types Pois Chiches Nos. 4732, 199 and 281 were selected for detailed study, and for convenience of reference these are re-named F 8, F 9 and F 10 respectively.

TABLE I

Relative resistances of types and collections of gram to Mycosphaerella rabie

Types and collections	Number of samples	Nature of infection
Indian types—		
Punjab types 1-26	26	All very susceptible and were totally killed by the disease. Type 1 was relatively less susceptible than the other types and took longer to be killed. Type 1 has white seed and is called '*Kabuli*' in Hindustani
Pusa types 1-84	84	All very susceptible and were totally killed by the disease
Nagina Bijnaur types 1-16 . .	16	Do.
Burma types 1-5	5	Do.
Shikarpur types 1-12	12	Do.
Punjab selections—		
S_2, S_4, S_5, S3A, S3B, S 7/2, S 7/3, S 7/4, S 7/5, S 7/6	10	Do.
Miscellaneous Indian types and collections—		
Red Guar Local	1	Do.
Collection from Western Tellinga division, Hyderabad	1	Do.
Gram from Raichur	1	Do.

Table I—*contd.*

Types and collections	Number of samples	Nature of infection
Purnbyn, Karachi 1933 (1)	1	Very susceptible and was totally killed by the disease
From Parbhawan, N. S. R.	1	Do.
Penbhatia gram	1	Do.
From Cereal Breeding Station, Nasik	1	Do.
Nasik, Hindi selected No. 1932-33	1	Do.
No. 1, W. Khandeshi	1	Do.
No. 2, W. Khandeshi	1	Do.
From Satara	1	Do.
Burma Gram from Dharwar, 1932-33	1	Do.
Dharwar Farm local gram	1	Do
Karachi special 3110 No. 5	1	Do.
Karachi special 123 No. 4	1	Do.
Karachi special 3116 No. 3	1	Do.
Karachi special No. 312 No. 2	1	Do.
Red Jacobabadi No. 1	1	Do.
Ambala A_6	1	Do.
Bhera A_3	1	Do.
Double R	1	Do.
Ferozepore samples	4	Do.
F 1	1	Do.
Kiloi 1	1	Do.
Lahore C_6	1	Do.
12 L D/2A, 12 L D/2B, 12 L D/3, 14 L D/2(a) and 14 L D/2(b)	5	Do.
Multan A_2	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Bengal Malda 2 samples	2	Very susceptible and was totally killed by the disease
Bharatpur samples Nos. 2, 5, 22	6	Do.
Bharatpur Local 1, 3 and 4		
Cawnpore	1	Do.
Central Provinces samples Nos. 1, 28, 34, 62, 288, 351 and 352	7	Do.
Coimbatore samples 19, 416, 468 and 482	4	Do. C 416 less susceptible than others though ultimately severely attacked
Coimbatore selection Nos. 4, 5, 6, 8, 9 & 11	6	All very susceptible and were totally killed by the disease C S 11 less susceptible than others though ultimately severely attacked
Indore sample	1	Very susceptible and was totally killed by the disease
Karachi samples	2	Do.
Nadiad Sirsa sample	1	Do.
Nadiad sample No. 2	1	Do.
Pondicherry sample	1	Do.
Frontier types 1-8	8	Do.
Parachinar S_1 and S_2	2	Do.
Tarnab sample	1	Do.
Sabour local sample	1	Do.
Sabour types 5, 6 and 7	3	Do.
Cuttack, Orissa S_1 and S_2	2	Do.
Sukkur White S_1 and S_2	2	Do.
Amritsar S_1	1	Do.
Bangalore sample	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Isthana S_1	1	Very susceptible and totally killed by the disease
Viramgam sample	1	Do.
Bagalkot sample	1	Do.
Sholapur S_1 and S_2	2	Do.
Broch sample	1	Do.
Gadag S_1 and S_2	2	Do.
Khandesh E sample	1	Do.
Poona sample	1	Do.
Ahmedabad sample	1	Do.
Foreign types—		
Roma types 1-3	3	All very susceptible and were totally killed by the disease. Roma No. 1 was relatively less susceptible than the other two types. This is like the Punjab white '*Kabuli*'
Catterda Ambulante di Agricole Napoli Nos. 1-8	8	All very susceptible and were totally killed by the disease. No. 7 was relatively less susceptible
Stazione Agaria Experimentale Bari, Nos. 1-4	4	Very susceptible and was totally killed by the disease
Pois Chiches No. 281	1	Very resistant. This is now called in the Punjab F 10
Pois Chiches No. 199	1	Very resistant. This is now called in the Punjab F 9
Pois Chiches No. 180	1	Fairly resistant
Pois Chiches No. 4732	1	Very resistant. This has been named F 8 and has been selected for introduction in the Punjab and is being multiplied
Pois Chiches Tobanda	1	Susceptible and killed by the diseas
Pois Chiches Ghafrai	1	Do.
Gram imported into Boston, U. S. A. from Italy (Plarius)	1	Do.

TABLE I—*contd.*

Types and collections	Number of samples	Nature of infection
Gram imported into U. S. A. from Italy	1	Fairly resistant
Gram imported into U. S. A. from Sonora Mexico	1	Susceptible and killed by the disease
Gram imported into U. S. A. from East Mexico	1	Do.
Gram imported into U. S. A. from Italy		Do.
Pois Chiches 84084	1	Less susceptible than others when young though ultimately severely attacked
Pois Chiches 84086	1	Do.
Gram from Alexanderoply. . .	1	Do.
Gram from Australia . . .	1	Susceptible and killed by the disease
Gram types from Baghdad, Nos. 1, 3, 4, 6, 7, 8, 9, 13, 16, 17, 18 and 19	12	Do.
Gram from Bratislavia . . .	1	Do.
Gram from Bulgaria . . .	1	Less susceptible than others though ultimately severely attacked
Gram from Ceylon, samples 1—2 .	2	Susceptible and killed by the disease
Gram from Egypt, samples 1—5 .	5	Sample No. 3 less susceptible than others though ultimately severely attacked
Gram from Greece, samples 1—9 .	9	Sample called Greece mixture less susceptible than others though this was also severely attacked
Gram from Palestine, samples 1—4 .	4	Susceptible and killed by the disease
Gram from Russia, samples 1—4 .	4	Do.
Gram from Sodovo	1	Infection moderate to severe, produced some grains
Rumania, S_1, S_2 and S_3 . . .	3	On S_3 infection traces to severe, others killed
Portugal, S_1 and S_2	2	Killed by the disease
Compoinsonza	1	Do.

TABLE I—*concld.*

Types and collections	Number of samples	Nature of infection
Urozekbez, S_1 and S_2	2	Infection on S_1 moderate, and on S_2 moderate to severe. Both produced some grains
Malta	1	Killed by the disease
Candia, S_1 and S_2	2	Do.
Morocco, S_1, S_2, S_3 and samples 1-6	9	Infection on S_2 moderate to severe and produced some grains. S_1, S_3 and samples 1-6 were killed
Morocco Rabat	1	Killed by the disease
Cairo, S_1 and S_4	2	Do.
Tunisie, S_1-S_9	9	Do.
Addis Ababa S_1-S_3	3	Infection on S_1 severe, but produced some grains; S_3 totally killed
Nyasaland	1	Killed by the disease
Somaliland, S_1 and S_2	2	Do.
Rhodesia, S_1-S_3	3	Do.
Algeria, 2 samples and 418	3	Do.
Libanizi	1	Do.
Persia, S_1, S_3, S_4, S_8, S_{10}, S_{11}, S_{12}, and S_{14}	8	Infection on S_3 and S_{11} moderate to severe and these two produced some grains, while the others were killed
U.S.A. 606 B, 606 C, 606 D, 607, 609 A, 609 B, 609 C, 610 A, 610 B, 613 A, 619 A, and one large seeded	12	Killed by the disease
Washington	1	Do.
Lima, S_1, S_2 and S_3	3	Do.
Versailles	1	Do.
Palestine S_5	1	Do.

C. RELATIVE RESISTANCE OF THE THREE SELECTED TYPES

(i) *Inoculations by spraying spore suspension*

The detailed observations (average of three years) on the relative infection of the three selected types (F 8, F 9 and F 10) when artificially inoculated by spraying with a suspension of spores of the causal fungus are recorded in Table II.

It will be seen that not a single plant of F 8, F 9 or F 10 was killed by the disease, whereas all plants of Pb T 7 and Pb T 15 were killed. It was, however, observed that plants of F 8 got slight traces of infection. The lesions were faint and superficial and often bore no pycnidia. This slight infection did not cause injury.

As regards relative resistance, F 10 is the best, F 8 is intermediate and F 9 is rated third. It is estimated, however, that none of the three types can be regarded absolutely immune from the disease. These types ripened satisfactorily with well-developed pods filled with normal seeds. Moreover in the inoculation tests referred to above the most favourable and rigorous conditions for the development of the disease were provided artificially, which in nature can seldom be present.

TABLE II

Relative resistance of the three selected types of gram

Method of inoculation	Types of gram	Percentage of plants killed	Percentage of branches killed	Percentage of pods killed
1. Spraying spore suspension	F 8	0	0	0
	F 9	0	0	0
	F 10	0	0	0
	Pb T 7	100	All the plants killed	
	Pb T 15	100	All the plants killed	
2. Spreading blighted debris over the plants	F 8	0	0	0
	F 9	0	0	0
	F 10	0	0	0
	Pb T 7	100	..	..
	Pb T 15	100	..	..
3. Sowing seed mixed with blighted gram plant debris	F 8	0	0	0
	F 9	0	0	0
	F 10	0	0	0
	Pb T 7	100	All the plants killed	
	Pb T 15	100	All the plants killed	

(*ii*) *Inoculations by spreading blighted gram debris over the plants*

The results of inoculation experiments by spreading blighted gram plant debris on the three types F 8, F 9 and F 10 are also given in Table II. These are similar to those obtained when inoculations are done by spraying spore suspension from a pure culture of the fungus.

(*iii*) *Healthy seed mixed with blighted debris*

Experiments were conducted to see how far the disease could be transmitted by healthy seed mixed with blighted debris. The results of such experiments are given in Table II.

It is clear that when blighted debris is mixed with seed, infection appears in the seedlings and the extent of the infection is almost the same as when inoculations are done by spraying spore suspension or spreading blighted debris on the plants. All the plants of Pb T 7 and Pb T 15 were killed.

D. FURTHER RESISTANCE TESTS WITH THE THREE SELECTED TYPES

In order to test the resistance of the selected types at all stages of their growth and under different environmental conditions the following experiments were conducted. In all these experiments the selected types F 8, F 9 and F 10 were grown side by side with Pb types 7 and 15 unless otherwise stated.

(*a*) *Resistance at different stages of growth*

In this connection two experiments were conducted.

EXPERIMENT (i).—The five types, i.e. F 8, F 9, F 10, Pb T 7 and Pb T 15 were sown on 25 October 1936 in nine series of plots, and each series was inoculated at fortnightly intervals beginning from 1 December 1936 to 1 April 1937.

EXPERIMENT (ii).—The five types were sown in six series on different dates at fortnightly intervals beginning from 25 October 1936 to 10 January 1937, and all the series were simultaneously inoculated on 15 February 1937.

The results, which were recorded on 2 April 1937, showed that in both the experiments Pb types 7 and 15 caught severe infection and were totally killed, whereas F 8, F 9 and F 10 had only traces of infection and no harm was done to any part of the plant. The experiment was repeated in 1937-38 and similar results were obtained. It is, therefore, concluded that F 8 and F 10 are resistant to blight at all stages of their growth.

(*b*) *Resistance when manured with different fertilizers*

Six sets of plots were prepared and the following fertilizers were added :—

(1) Ammonium sulphate at 200 lb. per acre
(2) Superphosphate at 125 lb. per acre
(3) Potassium sulphate at 50 lb. per acre
(4) Complete (Superphosphate 72 lb., ammonium sulphate 144 lb. and potassuim sulphate 72 lb. per acre)
(5) Farmyard manure at 200 mds per acre
(6) Unmanured.

The five types were sown in the various plots on 28 October 1937. They were inoculated on 15 March 1938 and observations were recorded on 18 April 1938. The results were that in all the plots Pb types 7 and 15 were killed, whereas F 8, F 9 and F 10 resisted the disease.

(c) *Resistance under different amounts of irrigation and rainfall*

F 8 and Pb type 7 were sown on 28 October in two series of plots. In the first series the plots received 0, 1, 4, 6, 8 and 10 in. of irrigation up to 4 April 1938, when all the plots were inoculated. These plots were protected from rain by covering them with thick *sarkanda* screens, when rain was expected.

In the second series, which had to receive different amounts of natural precipitation only, five sets of plots were arranged. The first set received no rain, and the remaining ones received 1·1, 2·1, 3·3 and 5·4 in. of rain respectively up to the 4 April 1938. In this series also the plots, after they had received a certain amount of rain, were protected from further precipitation in the same manner as in the first series.

The results as recorded on 20 April 1938 showed that Pb T 7 was totally killed, and F 8 resisted the disease.

(d) *Resistance of the crop when grown in different localities*

F 8 along with Pb T 7 was grown at Lyallpur, Gurdaspur and Campbellpur in November 1936 and inoculated in March 1937. The results were that at all the three places Pb type 7 was totally killed and F 8 remained resistant to the disease.

The experiment was repeated in 1937-38 at Lyallpur, Campbellpur and Samli (Murree hills) and the results were similar.

(e) *Inoculation tests under adverse conditions for growth of gram*

In order to find out if F 8, F 9 and F 10 maintained their power of resistance, when grown under unfavourable conditions of light and aeration, two experiments were conducted for two years.

In one experiments the five types were sown on the 25 October 1936 and were allowed to grow normally up to 1 February 1937, when high *sarkanda* screens were erected around each plot close to the plants. Though the plots were kept open from above, yet the height of the screen always kept the plants under shade. These were inoculated on 10 March 1937.

In the other experiment the types were sown on 10 February and immediately after they germinated they were shaded similarly as above. These were also inoculated on 10 March 1937.

The experiment was repeated during the 1937-38 season on the same dates.

In both the series the plants produced soft and succulent shoots. Their stems and branches elongated abnormally, became slender and almost prostrated on the ground. The leaflets underwent a considerable reduction in size, and their colour became light green.

The results for both the years are summarized in Table III.

Table III shows that in both the series both the Pb types 7 and 15 caught severe infection and died. On the other hand, not a single plant of F 8, F 9 and F 10 was killed though, due to their extremely enfeebled state, they caught considerably more infection than under normal conditions.

TABLE III

Results of inoculation tests under adverse and normal light conditions (1936-37 and 1937-38)

Year	Gram types	Normal			Adverse		
		Percentage of plants killed by blight	Percentage of branches killed	Percentage of pods killed	Percentage of plants killed	Percentage of branches killed	Percentage of pods killed
1936-37	F 8	0	0	0	0	0	0
	F 9	0	0	0	0	0	0
	F 10	0	0	0	0	0	0
	Pb T 7	100	..	..	100	..	..
	Pb T 15	100	..	..	100	..	..
1937-38	F 8	0	0	0	0	0	0
	F 9	0	0	0	0	0	0
	F 10	0	0	0	0	0	0
	Pb T 7	100	..	..	100	..	..
	Pb T 15	100	..	..	100	..	..

From the experiments described under Section II B, C and D, it is quite evident that the three types Nos. 4732, 199 and 281, which are termed F 8, F 9 and F 10 respectively, are resistant to the blight disease at all stages of their growth and under different environmental conditions. They have also remained resistant whether inoculated artificially by a spore suspension, by spreading blighted gram plant debris on the plants or when raised from seed with which blighted debris was mixed. Even when these types were grown under unfavourable conditions of light and aeration, they showed a high degree of resistance to the disease. In all the inoculation experiments, not a single plant of any of these types was killed by the disease, whereas all the plants of the local selected types Pb 7 and 15 were destroyed by it.

As regards relative resistance, F 10 comes first, F 8 is second and F 9 is third.

E. CHARACTERS OF THE SEED OF THE THREE RESISTANT TYPES

The seed of F 8 is yellow and has a rough surface. The seed resembles Pb 7, but its weight is about 1½ times as great.

The seed of F 9 is dull white in colour, has a smooth surface and is of medium size. Its weight is about 1½ times that of the usual type.

The seed of F 10 is black with a slightly rough surface. Its weight is 2¼ times that of the usual type.

F. YIELD PERFORMANCE OF THE RESISTANT TYPES

About one ounce of seed of each of these three types, F 8, F 9, and F 10, among others was supplied by the Bureau of Plant Industry, Washington, U. S. A. They were grown at Campbellpur. These three types gave indication of high resistance to blight in the first year of trial in 1933 and single plant selections were made. The isolation of vigorous plants and those well adapted to the climate was continued every year. In the 1935-36 crop, enough seed of these types was raised to lay out experiments on field scale with a view to examining their yielding capacity. During the *rabi* (winter) season of 1936-37 the three resistant types, viz. F 8, F 9 and F 10, were grown at Campbellpur side by side with the Punjab gram types Nos. 7, 15, 4, 25 and local (a mixture of Punjab types 17 and 19) in regular plots each measuring 85 ft. 1 in. × 16 ft. (1/32 acre in area). There were eight replications of F 8 (the yellow-seeded variety) against seven each of the Punjab types 7 (yellow seeded), 15 (yellow seeded) and local (brown seeded). Only five replications of F 9 (white seeded) and three of F 10 (black seeded) could be arranged against five of Pb 4 (white seeded) and three of Pb 25 (black seeded) respectively. Sowing was done on 10, 11 and 12 October 1936.

In 1937-38 only F 8 was compared with Pb 7 and 15. The area of each plot was 1/60 acre (11 ft. × 66 ft.) and there were ten replications. Sowing was done on 18 and 19 October 1937.

The seed rate was calculated on the basis of the absolute weight of the seed of the various types in order to get a comparable crop of equal stand of each. Seeds of F 8, F 9 and F 10 are 1·5, 1·56 and 2·25 times respectively as heavy as those of Punjab type 7. The standard seed rate of Pb 7 is 16 seers (32 lb.) per acre. Therefore, the seed rate used was 24 srs. (48 lb.) for F 8, 25 srs. (50 lb.) for F 9 and 36 srs. for F 10 per acre.

GERMINATION.—Good and uniform germination was obtained in all the plots except in those of F 10 which germinated irregularly even up to one month after sowing on account of the preponderance of hard seeds in it. The germination of F 8 took place about a couple of days later than that of Pb 7, and F 9 emerged almost at the same time as Pb 7.

YIELD.—The yield data are given in Tables IV and V.

In 1936-37, all the Punjab types included in the field trials were totally wiped out by the blight disease and did not yield even a single grain. F 8 on the other hand yielded 1165 lb. per acre.

In 1937-38, F 8 yielded on an average 1140 lb. per acre and Pb 7 and 15, 420 lb. and 108 lb. per acre respectively. From these figures it is clear that under Campbellpur conditions F 8 is far superior to Pb 7 or Pb 15.

TABLE IV

Yield of grain (lb.) of F 8, F 9, F 10, Pb 7 and 15 during 1936-37

(Area of each plot 1/32 acre)

Serial No.	F 8	F 9	F 10	Pb 7	Pb 15
1	51	8	10	0	0
2	32	4	6	0	0
3	40	4	14	0	0
4	15·5	3			
5	32·5	14			
6	42·0				
7	41·0				
8	37·0				
Average yield per plot in lb.	36·4	6·6	10	0	0
Average yield per acre in lb.	1,165	211	320	0	0

G. SELECTION OF F 8 FOR DISTRIBUTION TO FARMERS

The seed of F 8, being similar to the premier Punjab types (Pb 7 and 15 which are already being recommended by the Agricultural Department and are actually grown by the farmers in the province, is liked by the farmer. This type, as the above experiments show, has proved satisfactory as regards yield, and thus fulfills one of the crucial tests usually applied to determine the value of newly evolved strains from the viewpoint of the farmers, i.e. enhanced return per acre. The most significant and priceless asset of the type is its ability to withstand the destructive blight disease, on account of the prevalence of which the cultivation of gram in the north and submontane districts of the Punjab has become problematical. The poor farmer of the greater part of this tract particularly in the north Punjab has been threatened with the loss of a crop which is his only means of subsistence. Gram is the life and soul of the people, and blight has been a calamitous visitant and a great menace for long in this part of the country. The selection of the resistant strain is a priceless boon to them and the surrounding area, including the North-West

Frontier Province, where also the disease has taken a strong hold. Of the three resistant types, F 8 has been selected as the most suitable for introduction into the husbandry of the province as a new production to replace the local seed and combat the blight disease.

TABLE V

Yield of grain (lb.) of F 8, Pb 7 and Pb 15 during 1937-38

(Area of each plot 1/60 acre)

Replications	F 8	Pb 7	Pb 15
I	22	4·0	2·5
II	18	10·5	2·0
III	21	6·5	2·2
IV	16	9·0	4·0
V	19	6·0	0·5
VI	20	6·0	0·5
VII	21	5·5	0·5
VIII	12·5	6·0	1·5
IX	20·0	8·5	2·0
X	21·0	8·0	3·0
Average yield per plot in lb.	19·0	7·0	1·8
Average yield per acre in lb.	1,140	420	108

In 1938, about 60 mds (1 maund = 82·3 lb.) seed of this type was produced. The whole of it was sown at the Agricultural Farms, Risalewala (Lyallpur), Sargodha, and Campbellpur and 1235 mds of seed became available in 1939. This is being further multiplied under strict supervision, and it is expected that in 1940 about 25,000 mds of seed of this type will be in hand for supply to farmers and thus it will be possible to replace the local seed by F 8 in all the blight-affected areas of the province in two or three years.

III. SUMMARY

1. Three hundred and ninety-two types and collections of gram obtained from different places in India and foreign countries have been tested as regards their relative resistance to the blight disease of gram (*Mycosphaerella rabiei=Ascochyta rabiei*).

2. All the Indian types have been found susceptible to the disease and of the foreign types Pois Chiches 4732, No. 199 and No. 281, which are here called F 8, F 9, and F 10 respectively, showed high resistance to the disease.

3. The three types F 8, F 9, and F 10 have remained resistant under different environmental conditions.

4. Of the three resistant types, F 8 has given the best yield. This type also possesses other desirable characters.

5. F 8 has been selected for distribution to farmers in the blight-affected areas of the province. Its seed is now being multiplied, and it is expected that in 1940 about 25,000 mds of seed of this type will be available.

The authors wish to record their thanks to all the scientific workers in India and abroad, who very kindly supplied the seeds of different varieties of gram for this investigation.

REFERENCES

Luthra, J. C. and Bedi, K.S. (1932). *Ind. J. Agric. Sci.* **2**, 499-515

Luthra, J. C.; Sattar, A. and Bedi, K. S. (1935). *Agric. and Live-Stock in Ind.* **5**, 489-98

——————————— (1939). *Ind. J. Agric. Sci.* **9**, 791-806

Sattar, A. (1933). *Ann. Appl. Biol.* **20**, 612-32

BIOLOGY AND CONTROL OF WOOLLY APHIS *ERIOSOMA LANIGERUM* HAUSM (APHIDIDAE: RHYNCHOTA) IN THE PUNJAB

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I. Introduction

Woolly aphis (or American blight) is a native of America [Greenslade, 1936]. It was noticed in the Punjab for the first time in 1909 in the Simla district on young apple plants which had been imported from England [Misra, 1920]. The work on its biology and control was taken up in the Kulu Valley (Punjab) in 1934 and the results of these investigations are presented in this paper.

II. Distribution

Woolly aphis is confined to the hilly tracts of the Punjab and has so far been reported from the following localities: Simla, Mashobra, Kotgarh, Kotkhai, Solan, Kasauli, Jubbal State, and Koti State in the Simla district and Bajaura, Kulu, Bandrole, Niramiti, Raison, Shirir, Katrain, Dobi, Naggar, Karjan and Manali in the Kulu Valley.

III. Food-plants

Greenslade [1936] states that ' the chief hosts of woolly aphis are apple and American elm.' He further maintains that 'it has also been recorded from the following plants ' but ' some of these records may be due to faulty identification of the aphis '.—

Crataegus crus-galli
C. punctata
C. oxyacantha
C. cuneata
Pyrus toringo [*P.* (*Malus*) *sieboldii*]
P. (*Sorbus*) *americana*

P. americana var. *decora* (*P. sitchensis*)
P. malus var. *paradisiaca* (*P. malus* var. *pumila* or *P. pumila paradisiaca*
Cotoneaster horizontalis
C. acutifolia
Pyrus (*Malus*) *scheideckeri*
P. aucuparia
Cydonia vulgaris (*Pyrus cydonia*)
Pyrus communis
Salix sp.
Syringa vulgaris

In the Punjab woolly aphis is confined to apple and crab apple (*Pyrus baccata*, vernacular name *pala*). Efforts to find it on other plants as mentioned by Greenslade have been in progress since 1934, but up to this time the pest has not been found on any one of them. The varieties of elm—*Ulmus americana* and *U. campestris*—which are known to be its alternative host-plants in America are not found in the Punjab and a search for its presence on the varieties, *U. villichiana* and *U. lavigata*, found in the Kulu Valley yielded negative results.

A few plants of *Ulmus campestris* were obtained in 1936 through the courtesy of the Divisional Forest Officer, Murree. They were planted in a wire-gauze cage (measuring 10 ft. × 5 ft. × 5 ft.) which had a few heavily infested crab apple plants growing in it since December 1935. These elm plants were artificially inoculated with woolly aphis first in March 1936 and then regularly afterwards up to November 1937. The pest has never succeeded in establishing itself on *U. campestris* and it always perished in three to four days after inoculation. At the time of writing both the plants are still growing in the cage and the crab apple is seriously suffering, while *U. campestris* is absolutely free from woolly aphis.

IV. LIFE-HISTORY

Viviposition.—In America woolly aphis produces sexual forms before winter which lay eggs on elm bark [Patch, 1912]. These eggs hatch in spring when infestation starts. In the Punjab, on the other hand, the pest neither produces any sexual forms nor it migrates to the elm tree ; it viviposits throughout the year on apple. Moreover, in spite of our very careful and diligent searches extending over six years (1934-40), we have never found a male woolly aphis. Thus it is concluded that the woolly aphis in the Punjab does not produce any males, its reproduction being parthenogenetic and the parthenogenetically produced progeny consisting of females only.

Rate of reproduction.—The number of young produced by a female in her life-time depends upon the season : during November-February a female produces 48-87, and during March-November 30-116 young ones. The young ones are produced by instalments, a female resting for 4-24 hours during March-September and for eight hours to a week during November-February, after every parturition. The number of young produced by a female daily varies from one to six, the largest number of them being produced during July-August and the smallest during December-February. A female takes 7-12 minutes to give birth to one nymph.

TABLE I

Viviposition record of woolly aphis on apple at Kulu

(Number of observations made 110, but for brevity only 15 are mentioned)

Number	Female sleeved		Number of young produced		Total number of young produced by one female
	From	To	Daily	Weekly	
1	11 Mar. .	1 May .	1—5	..	30
2	,, .	,, .	1—5	..	112
3	20 May .	28 June .	1—5	..	50
4	,, .	,, .	1—5	..	73
5	2 Aug. .	8 Oct. .	1—6	..	116
6	,, .	,, .	1—6	..	74
7	,, .	,, .	1—6	..	108
8	,, .	,, .	1—6	..	85
9	6 Oct. .	21 Nov. .	1—4	..	91
10	,, .	,, .	1—4	..	71
11	,, .	,, .	1—4	..	62
12	15 Nov. .	27 April .	..	1—2	87
13	,, .	,, .	..	1—2	48
14	,, .	,, .	..	1—2	70
15	,, .	,, .	..	1—2	60

A nymph is born with the tip of its abdomen first. A newly born nymph becomes active within 15 minutes of its birth. The nymphs are gregarious and a large number of them fix themselves together on the plant either near about their mothers or away from them, the cotton wool appearing over their bodies 24 hours after fixation.

Nymphal instars.—There are four nymphal instars. The duration of each nymphal instar varies according to the season (Table II).

TABLE II

Duration of nymphal instars of woolly aphis during different months at Kulu

Serial No.	Born on or between	I instar Total duration (days)			II instar Total duration (days)			III instar Total duration (days)			IV instar Total duration (days)			Adults emerged between	Total duration of nymphal instar (days)		
		Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.		Min.	Max.	Av.
1	7-9 Jan.	31	32	31·5	18	18	18	10	10	10	7	7	7	14-15 Mar. . .	66	67	66·5
2	2-5 Feb.	19	21	20	9	9	9	8	8	8	4	4	4	14-18 Mar. . .	40	42	41
3	12-24 Mar.	9	17	13	5	10	7·5	4	8	6	2	4	3	13-22 April . .	20	39	29·5
4	3-10 April	8	9	8·5	6	6	6	3	3	3	2	2	2	22-30 April . .	19	20	19·5
5	8 May	4	5	4·5	2	3	2·5	1	3	2·0	1	2	1·5	16-21 May . .	8	13	10·5
6	1 June	4	5	4·5	3	4	3·5	3	3	3	1	2	1·5	12-15 June . .	11	14	12·5
7	1-5 July	5	7	6	4	5	4·5	3	4	3·5	3	3	3	16-24 July . .	15	19	17
8	8-17 Aug.	10	12	11	8	10	9	7	9	8·5	6	8	7	8-25 Sept. . .	31	39	35
9	3-7 Sept.	12	13	12·5	10	11	10·5	9	9	9	4	7	5·5	8-17 Oct. . .	35	40	37·5
10	1-3 Oct.	12	14	13	8	10	9	7	9	8	5	7	6	2-12 Nov. . .	32	40	36·0
11	2-3 Nov.	14	16	15	10	12	11	8	10	9	6	8	7	10-18 Dec. . .	38	46	42
12	5-8 Dec.	40	43	41·5	30	30	30	12	12	12	8	8	8	7 Mar. . . .	90	93	91·5

V. SEASONAL HISTORY

The seasonal-history of woolly aphis was studied at Raison and Kulu.

Raison (*height above sea level 4,500 ft.*).—The pest becomes active in March when the overwintered females start viviposition, while the overwintered nymphs reach maturity in the first week of March when they also start viviposition. The pest multiplies rapidly in summer both on the aerial parts and the roots of the infested plants. In May partial migration takes place from the roots to the aerial parts of the attacked plants. The winged forms, which begin to appear in July, reach their maximum abundance in September. Thus during August-September majority of the nymphs develop into winged females although wingless females are also produced during this period. The winged forms die off in October. The pest is most active (and destructive) during March-September. It multiplies at a reduced pace during October-December, both on the aerial parts and roots of the attacked plant. During December-February its multiplication slows down very considerably. In December there is a partial migration from the aerial parts to the roots of the infested plants.

Kulu (*height above sea level 4,000 ft.*).—At Kulu there is no migration either in summer or in winter from aerial parts to the roots and *vice versa* of an infested plant. Otherwise, the behaviour of the pest is identical with that at Raison.

VI. MIGRATION FROM AERIAL PARTS OF AN INFESTED PLANT TO ITS ROOTS AND *VICE VERSA*

At Raison migration from the aerial parts to the roots of an infested plant takes place during the period from mid-December to mid-January, the nymphs migrating only during the hotter part of the day. The stem of the infested plant gets covered with the white wax-covered bodies of the migrating individuals, with the result that it looks white from a distance. Their migration is, however, only a partial migration, because, at its close a very large number of the nymphs (majority of them full-grown) and a few females are found to spend the winter on the aerial parts of the infested plant.

Return migration of the pest from the roots to the aerial parts of an apple plant takes place in summer at Raison and continues throughout May, the migration being partial, for the nymphs and females of the pest remain on the roots of each one of the infested plants right through the summer season. Thus at Raison woolly aphis remains active, both on the roots and the aerial parts of an infested plant, throughout the year. At Kulu proper, on the other hand, there is no migration whatsoever, the pest remaining present on the aerial parts and roots of the attacked plant throughout the year.

VII. DISPERSAL

(1) The winged forms appear during July-October in the Kulu Valley. They fly to other apple plants and start new colonies on them.

(2) According to Greenslade [1936] nymphs are blown from tree to tree in loose masses of wool. We have observed the same phenomenon in the Punjab also.

(3) We have also observed that newly born nymphs are responsible for infesting healthy plants in an orchard. These nymphs fall off ' or are blown off the tree and walk to the next tree ' [Greenslade, 1936]. We have found the young nymphs to be capable of crawling over a distance of 20 ft. on the ground to reach another plant.

Dispersal of the pest in the manner described under 2 and 3 is at its maximum during July-September at Kulu.

VIII. DAMAGE

Greenslade [1936] has described succinctly several types of damage by this pest. Our experience is that : (1) fruit from a heavily attacked plant is of poor quality, being undersized, malformed and insipid in taste ; (2) damage to the aerial parts of a grown-up tree is more pronounced and serious than to roots, for the entire stem and most of the branches get covered with galls, this condition affecting the vitality of the plant adversely ; (3) roots near the surface of the soil are generally attacked and it is only in rare cases that the pest may go down as deep as 4 ft. In any case the damage to roots is not serious ; (4) Young nursery plants usually succumb to the attack of this pest.

IX. INSECT PREDATORS

Greenslade [1936] gives a long list of insects which prey upon woolly aphis in different parts of the world. Some of these predators, e.g. *Syrphus balteatus* De G., *Adalia bipunctata* L., *Coccinella septempunctata* L., etc. are also found in the Punjab, but they have not so far been found to prey upon woolly aphis in the Kulu Valley and Simla Hills where it is preyed upon by the following predators :—

i. *Ballia eucharis* Muls.
ii. *Coleophora sauzeti* Muls.
iii. *Chilomenes bijugans infernalis* Muls.
iv. *Syrphus confrater* Weid.
v. *Coniocompsa indica* Withycombe.
vi. *Ancylopteryx punctata* Hag.

A brief account of each one of these predators is given below :—

(i) *Ballia eucharis* Muls. (Fig. 1) (Coccinellidae : Coleoptera).—This beetle is about 8 mm. long and about 7 mm. broad. It is dirty yellow in colour and each one of its elytra is ornamented with four black spots which are arranged as shown in the figure.

It is present on the plants infested with woolly aphis during summer only. It is never abundant and, as such, does not exercise any check on the pest.

(ii) *Coleophora sauzeti* Muls. (Fig. 2) (Coccinellidae : Coleoptera).—This beetle is about 4 mm. long and about 3 mm. broad. It is dirty yellowish in colour. Its pronotum is ornamented with a saddle-shaped black mark and each of its elytra is ornamented with one longitudinal stripe and four black dots as shown in the figure.

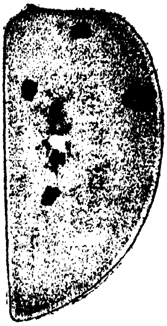

FIG. 1. Elytra of *Ballia eucharis*

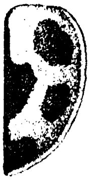

FIG. 2. Elytra of *Coleophora sauzeti*

It is present among woolly aphis colonies during August-September. Like *B. eucharis* Muls., it also does not exercise any check on the pest.

(iii) *Chilomenes bijugans infernalis* Muls. (Fig. 3) (Coccinellidae : Coleoptera).—This beetle is 5 mm. long and 4 mm. broad. It is shining dark brown in colour with two large, oblong and two small, round light blood-red spots on elytra as shown in the figure.

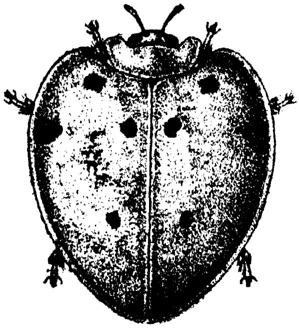

FIG. 3. Adult of *Chilomenes bijugans infernalis* Muls. (× 8)

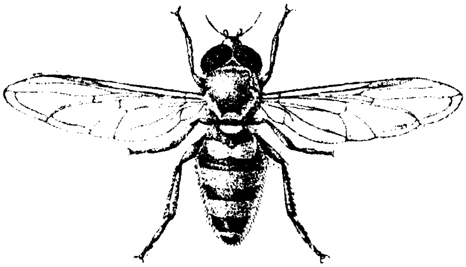

FIG. 4. Adult of *Syrphus confrater* Wd. (× 3)

It is active from March to November, but during December-February it hibernates both as pupa and adult. During spring it completes its life-cycle in 60 days as follows : egg stage, not known (but eggs collected from fields hatched in two to three days) ; larval stage 40 ; pupal stage 15 days.

This beetle is most common during May-July, when it exercises a definite check over woolly aphis. It is parasitized by *Tetrastichus* sp. (Eulophidae : Hymenoptera) which is not yet identified to species.

(iv) *Syrphus confrater* Wd. (Fig. 4) (Syrphidae : Diptera).—The adult is 8-11 mm. long. Dorsum of its thorax is 'steely aeneous' while the first segment of its abdomen is black and abdominal segments three to four with yellow and black transverse bands as shown in the figure.

This is a very common syrphid in the Kulu Valley which hibernates as a pupa. It is abundant specially during the period from June to September-October. Its life-cycle is completed in 26-30 days. It keeps the pest in check, particularly during July-September.

(v) *Coniocompsa indica* Withycombe (Coniopterygidae : Neuroptera).—This predator is of very rare occurrence in the Punjab, and as such does not exercise any check on woolly aphis.

(vi) *Ancylopteryx punctata* Hag. (Fig. 5) (Chrysopidae : Neuroptera).—Adult measures 8 mm. in length and is 25 mm. in the wing expanse. Its body is shining light green and is furnished with a creamy white longitudinal mid-dorsal line. Antennae are yellowish and the wings hyaline with veins light green.

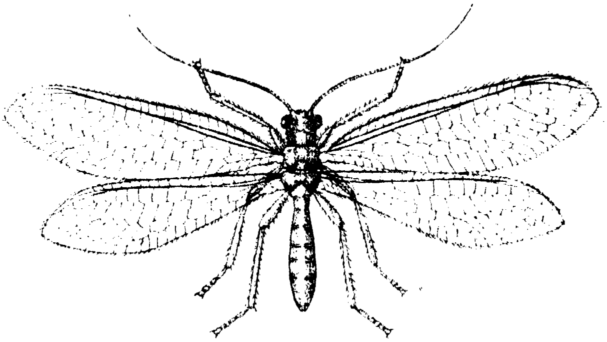

FIG. 5. Adult of *Ancylopteryx punctata* (×3)

This is a common predator in the Kulu Valley. It is active during April-November but during December-March it hibernates as pupa. Its life-cycle is completed in three to four weeks. It is most abundant during April-June and September when it exercises a definite check on the pest.

X. CONTROL MEASURES

INSECTICIDAL CONTROL

a. Control of aerial forms

(i) Greenslade [1936] recommends spraying the infested plants with : (1) 20 per cent of tar distillates, or (2) 4 per cent petroleum sprays in the dormant period and by 1 per cent summer oil sprays with or without the addition of nicotine in the summer. Some workers have also recommended kerosene oil emulsion against this pest. These insecticides together with those commonly employed in the Punjab [Rahman, 1940] were tried and discarded in favour of rosin soap. This soap was prepared by us as follows :—

Mohwa (*Bassia latifolia*) oil . . .	**21 seers**
Caustic soda	**7 seers**
Rosin	**32 seers**
Water	**25 seers**

Three seers of caustic soda were dissolved in 10 sr of water and 21 sr of *mohwa* oil were added to the solution which was stirred well. It was left overnight to form soap.

The remaining 4 sr of caustic soda were dissolved in the remaining 15 sr of water. The 32 sr of rosin were powdered and added to this solution. The soda-rosin mixture was boiled until rosin was completely dissolved and the mixture assumed a dark brown colour. Soap (formed by *mohwa* oil and caustic soda) was cut up into thin slices and added to this dark brown caustic-rosin mixture and boiled until a homogeneous mixture was obtained. This mixture was allowed to cool and set.

TABLE III

Effective concentration of rosin soap for woolly aphis

(Number of experiments carried out 20, but for brevity only 5 are given below)

Quantity (in chhataks) dissolved in 20 seers of water	Number of living aphids (all stages) per shoot before spraying	Number of dead aphids (all stages) per shoot after spraying	Per cent mortality
3	325	95	29
4	425	192	45
5	614	516	84
6	521	495	95
7	365	365	100

It is seen from Table III that rosin soap when used at the rate of 7 ch. in 20 sr of water gave cent per cent mortality.

(ii) *Smudging.*—Fumes of creosote and sanitary fluid were tried as smudges during September-October in fine weather. These chemicals were poured on smouldering heap of leaves placed under the infested limb of a plant where they produced a dense column of smoke. The results are presented in Table IV.

TABLE IV

Efficiency of creosote and sanitary fluid as smudges against wooly aphis

(Exposure for two hours)

Chemical	Quantity (in oz.) per tree	Number of living aphids per colony before smudging	Number of dead aphids per colony after smudging	Per cent mortality
Creosote .	1	232	*Nil*	*Nil*
	2	167	..	..
	3	135	..	..
	4	212	..	..
	6	67	..	..
	8	335	..	..
Sanitary fluid	1	212	..	..
	2	198	..	..
	3	115	..	..
	4	174	..	..
	6	215	..	..
	8	235	..	..

It will be observed from Table IV that creosote and sanitary fluid as smudges are entirely useless against woolly aphis.

b. Control of root-infesting forms

Insecticides tried to control the root-infesting forms are discussed below :—

(i) *Paradicholorobenzene*.—It proved very effective against the root forms : it also killed the migrating individuals at Raison during December-January and in May. The poison was applied in a 4-in. deep trench covered with earth. The results are presented in Table V.

(ii) *Calcium cyanide*.—It also proved very effective, but was neither so lasting nor so cheap as P. D. B. Besides, it had no effect on the migrating forms.

The results are presented in Table VI.

TABLE V

Efficiency of paradicholorobenzene (P. D. B.) against woolly aphis

(P. D. B. sells at 0-4-3 per oz.)

(Number of experiments carried out 172, but for brevity only 18 are given below)

Date of application	Quantity applied (in oz.) per tree	Radius of the ring (in ft.)	Age of the tree (in years)	Per cent mortality	Remained effective for
17 Dec. . .	½	5	12	75	1½ months
	1	5	12	100	,,
	2	5	12	100	,,
	3	5	12	100	,,
21 Jan. . .	¼	2	3	82	,,
	⅓	2	3	100	,,
	½	2	3	100	,,
26 Jan. . .	1	5	12	100	,,
	2	5	12	100	,,
18 Feb. . .	2	5	10	100	,,
	4	10	25	100	,,
17 May . .	2	5	12—15	100	3 weeks
	2	5	12—15	100	,,
	4	10	26	100	,,
	4	10	26	100	,,
	1	5	5	100	,,
	1	5	5	100	,,
	1	5	5	100	,,

TABLE VI

Efficiency of calcium cyanide against woolly aphis

(Calcium cyanide sells at Rs. 1-12 per lb.)

(Number of experiments carried out 475, but for brevity only 7 are given below)

Date of application	Quantity applied (in oz.) per tree	Radius of the ring (in ft.)	Age of the tree (in years)	Per cent mortality	Remained effective for
21 Jan. . .	⅓	2	3	90	One week
	½	2	3	95	,,
	1	5	12	95	,,
	2	5	12	100	,,
18 Feb. . .	2	5	8—12	100	,,
	4	10	25	100	,,
17 May . .	2	5	12	100	,,

Contrary to the observations of Reppert, Schoene, and Underhill [Greenslade, 1936], calcium cyanide did not cause any damage to the roots of the trees under experiments.

(iii) *Carbon bisulphide.*—This was applied with the 'soil injector'. It gave cent per cent mortality round about the place of injection (duration of effectiveness =3-4 days), but aphids away from the place of injection were not at all affected by it. It was not so effective as P. D. B. or calcium cyanide.

(iv) *Sanitary fluid.*—It proved as effective as P. D. B. and in the soil its effect lasted for about three weeks. It killed 100 per cent of the root forms, but produced no harmful effects on the roots. It is, however, very costly and can only be applied in localities where plants are regularly irrigated. The results are presented in Table VII.

TABLE VII

Efficiency of sanitary fluid against woolly aphis

(Sanitary fluid sells at Re. 1 to Rs. 2 per gallon)

(Number of experiments carried out 11, but for brevity only 5 are mentioned)

Date of application	Quantity applied (in gallons) per tree	Radius of the ring (in feet)	Age of the trees (in years)	Per cent mortality	Remained effective for
17 Dec. . .	$\frac{1}{4}$	5	12	85	two weeks
	$\frac{1}{2}$	5	12	85	,,
	1	5	12	95	,,
17 May . .	$\frac{1}{2}$	5	12	81	One week
	1	5	12	98	,,

(v) *Powdered naphthalene.*—This was applied like P. D. B. It gave very low mortality indeed and did not damage the roots of the treated trees. The results are presented in Table VIII.

TABLE VIII

Efficiency of powdered naphthalene against woolly aphis

(Number of experiments carried out 20, but for brevity only 4 are mentioned)

Date of application	Quantity applied (in lb.) per tree	Radius of the ring (in ft.)	Age of the tree in years	Per cent mortality	Remarks
15 Nov. . .	1	5	10	3	Mortality was observed only in cases when naphthalene powder was quite close to the colonies.
	2	5	10	7—8	
	3	5	10	15	
	4	5	10	17—18	

(vi) *Tobacco dust*.—Contrary to Greenslade's [1936] assertion, tobacco dust did not prove useful at all. When the roots were opened up after the treatment, it was found that the dust did not affect the root forms in any way. Migration of root forms from the treated trees took place as usual.

TABLE IX

Efficiency of tobacco dust against woolly aphis

(Number of experiments carried out 19, but for brevity only 7 are given below)

Date of application	Quantity applied (in sr) per tree	Radius of the ring (in ft.)	Age of the trees in years	Per cent mortality
26 Jan.	¼	5	3	*Nil*
	½	5	3	*Nil*
	1	5	12	*Nil*
	2	5	12	*Nil*
	3	5	12	*Nil*
17 May	4	5	12	*Nil*
	6	5	12	*Nil*

ACKNOWLEDGEMENTS

This line of work was suggested by M. Afzal Husain, Entomologist to Government, Punjab, Lyallpur and to him we are grateful for helpful suggestions until his appointment as Vice-Chancellor of the Punjab University in 1938.

XII. SUMMARY

Woolly aphis (*Eriosoma lanigerum* Haus.) is a native of America. It was noticed in the Punjab for the first time in 1909 in the Simla district on young apple plants which had been imported from England. It is found in the Simla Hills and the Kulu Valley exclusively on apple.

Reproduction in this pest takes place by parthenogenesis, the progeny consisting of females only. The nymphs reach maturity in 8-19 days during May-July. The number of young produced by a female depends upon the season, but the largest number of them are produced during July-August.

Woolly aphis attacks both aerial parts and the roots of the apple plant. Migration of the aerial forms to the roots and *vice versa* depends upon the altitude of the locality ; at Kulu there is no migration, but at Raison there is a partial migration during December-January and in May. The winged forms appear in July-October when they fly to healthy plants and start new colonies. The pest is also spread through the agency of wind.

The attacked plant yields fruit of poor quality.

Of the insect predators of woolly aphis discussed in this paper *Chilomenes bijugans infernalis* Muls., *Syrphus confrater* Wd. and *Ancylopteryx punctata* Hag. exercise definite check on it.

The aerial forms of the pest can be effectively controlled by spraying them with rosin soap, while the root forms are best dealt with by paradicholoro-benzene.

REFERENCES

Greenslade, R. M. (1936). *Imp. Bureau Fruit Production Tech. Comm. No.* **8**

Husain, M. A. (1934-38). *Ann. Reports Ent. Govt. Punjab, Lyallpur* (for each year from 1934 to 1938)

Misra, C. S. (1920). *Agric. J. Ind.* **15**, 627

Patch, E. M. (1912). *J. Econ. Ent.* **5**, 395

Rahman, Khan A. (1938-40). *Ann. Reports Ent. Govt. Punjab, Lyallpur* (for 1938-39 and 1939-40)

Rahman, Khan A. (1940). *Punjab Agric. Coll. Mag.* (*Lyallpur*) **7**, Nos. 5-7 (Insect Pest Number)

STUDIES ON THE PERIODIC PARTIAL FAILURES OF PUNJAB-AMERICAN COTTONS IN THE PUNJAB*

III. THE UPTAKE AND THE DISTRIBUTION OF MINERALS IN THE COTTON PLANT

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(With 13 text-figures)

INTRODUCTION

THE symptoms exhibited by the American cotton plants suffering from the physiological disease known as *tirak* during the failure years resembled the symptoms of plants that suffer from some deficiency disease. The yellowing and reddening of the leaves and the immaturity of seeds are generally indicative of deficiency of some important mineral, like potassium or nitrogen. Such symptoms of deficiency disease are known to occur in many crop plants. It was thought probable that the American cotton plants in the Punjab also suffered from some disturbance in their mineral or nitrogen metabolism and developed the symptoms of the disease commonly designated as *tirak*. A study of the uptake of different minerals and nitrogen and their relative distribution, stage by stage, in the different parts of the normal 4F American cotton plant was, therefore, undertaken with a view to making a similar study later of the diseased plants, so that the nature and the time of any such disturbance in the mineral nutrition of the latter could be determined. The present paper relates only to the mineral uptake and its distribution in normal plants as it is first necessary to study the normal trends in the mineral nutrition of the plant to differentiate the abnormal features that may be present in the diseased condition. For the sake of completeness and comparison, the *desi* plants, which are generally not found to suffer from such a disease, are also included in this study. It may be mentioned here in passing that the mineral composition and its uptake stage by stage by the American and *desi* plants have not been determined in the Punjab, where cotton is the most important crop, and therefore this appeared to be an additional reason for undertaking the investigation in its present form.

The mineral composition of the cotton plant at one stage or the other has been determined by workers abroad [Hutchinson and Patterson, 1892; Fraps, 1919; McHargue, 1926]. White [1914-1915] found that maximum amounts of nitrogen, potassium and phosphorus were absorbed by the cotton plant at the blooming stage. Similar findings have also been reported by

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Kundrin [1929], Holley, Pickett and Dulin [1931], Armstrong and Albert [1931] and by Murphy [1936].

MATERIAL AND METHODS

The 4F American and Mollisoni *desi* plants were grown* in alternate rows to minimize the effects of soil heterogeneity in Square 10 of the Lyallpur Agricultural Farm. The soil was a sandy loam with 63·9 per cent of sand, 19·88 per cent of silt, 14·2 per cent of clay and 3 per cent of carbonates in the upper 3 feet. The soil reaction was at *p*H 8·1 and the total water-soluble solids were about 920 p.p.m. in the same layers. The land was fallow during the previous year. The sowing was done on 14 May 1935 and the plants were finally thinned on 9 July to 1½ ft. between the plants keeping one plant per hole. The distance between the rows was kept at 3 ft. In the case of the *desi* variety, the spacing between the plants was 1 ft. These spacings are the normal spacings adopted for the two varieties in the Punjab.

The plants were labelled at random for sampling. The samples were taken every fortnight. In the early stages, 30-40 plants had to be sampled, but this was reduced later to 10 plants. The samples were collected in the morning with roots up to a depth of 2½ ft. The fresh weights were recorded immediately after removal. Adhering particles of sand were removed and the different parts were chopped up into bits and a representative sample of each part was taken for determination of moisture. A second representative sample was dried in an electric oven at 40°-45°C. The samples after drying were powdered and kept in stoppered bottles for chemical analysis.

Standard A. O. A. C. methods of analysis were employed for determination of silica-free ash, nitrogen, potash, phosphoric acid, lime, magnesia, aluminium and iron. Sulphur and chlorine were determined gravimetrically and volumetrically respectively, care being taken to include sulphur and chlorine present in the organic form.

Sodium was determined as sodium-magnesium-urenyl acetate after removing all interfering ions. Manganese was determined by sodium bismuthate method, copper by potassium ethyl xanthate method and zinc by potassium ferrocyanide nepholometric method. 10-25 gm. of air-dried material were taken for ashing and subsequent analysis. For copper, zinc and manganese, 50 gm. of material had to be taken on account of very small quantities of these elements present in the plant. The analysis was made in duplicate.

PRESENTATION OF DATA

The results of analyses are discussed in two sections. Section 1 deals with the mineral composition of American and *desi* cotton plants at maturity. The uptake and distribution of different minerals in the whole plant and in its different parts, of each variety, at different stages of growth, are dealt with in section 2. The study of distribution of dry matter and moisture is also included in the latter. All results are expressed graphically.

The results of mineral and nitrogen contents were calculated and studied in more ways than one. The results were calculated per whole-plant basis and per each part of the plant, per 100 gm. of the whole plant and per 100 gm.

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*No effect on the growth of American varieties is noticeable either when they are grown mixed with *desi* cottons or as unmixed crop.

of each part of the plant, per 100 gm. of ash of the whole plant and per 100 gm. of ash of each part of the plant. The quantity of each mineral at different stages expressed as percentage of the total quantity absorbed by the whole plant was determined. The percentage distribution of each mineral in the different parts of the plant at different stages of growth was also determined. The relative rate of uptake of each mineral was arrived at from the formula $R=(\log M_2 - \log M_1)$ where M_1 and M_2 are the quantities of minerals at two consecutive stages of growth [Gregory, 1926].

STATISTICAL ANALYSIS OF THE DATA

The differences found between the various mineral contents of the American and *desi* plants could not be put to a statistical test as the analysis was not carried out on replicates at each stage. The Fishers '*t*' test could not therefore be applied. The analytical data given here form a time series, and consistent differences in some minerals in the two varieties at all stages of growth are found. Though the '*t*' test is not strictly valid in such cases, it is applied neglecting the effect of time, and significant differences are found between certain minerals in the two varieties. So, whenever a mention is made in the text of a particular difference as statistically significant, it is implied that the '*t*' test is applied to such a time series.

§ 1. *Mineral composition of the American and* desi *cotton plants*

The quantities of different minerals and nitrogen found in two varieties of the cotton plant are given in Table I per whole-plant basis and per 100 gm. of the whole plant. The differences in the quantities of minerals seen in the two plants, per whole-plant basis, are mainly due to the differences in their dry weights. The mineral contents of the two varieties at maturity per 100 gm. dry weight are nearly the same except in two cases. The American plant contains more potash and less lime and sulphates than the ***desi*** plant. Lime, potash, sulphates and nitrogen are found in largest amounts in each variety, while the remaining minerals are found in small quantities.

The above results of mineral contents of the cotton plants have been verified by analysing the cotton plants in succeeding seasons. It is found that there are small differences in the mineral contents of plant parts of a variety grown in different fields, but the trends in the uptake of a mineral at different stages of growth are found to be the same.

TABLE I

Mineral and nitrogen contents of American (24 December 1935) and desi *(26 November 1935) plants*

Variety	Dry wt	Silica-free ash	N_2	K_2O	CaO	MgO	Al_2O_3 + Fe_2O_3	P_2O_5	SO_4	Cl_2
					Gm. per plant					
4F American	864·7	69·47	14·52	17·84	19·37	3·79	0·49	3·02	12·95	2·72
Mollisoni *desi*	552·1	45·82	9·26	9·66	13·10	2·78	0·37	1·80	9·13	2·07
					Gm. per 100 gm. of the whole plant					
4F American	100	8·04	1·68	2·07	2·24	0·44	0·06	0·35	1·50	0·32
Mollisoni *desi*	100	8·30	1·68	1·75	2·36	0·51	0·07	0·33	1·66	0·38

Quantities of minerals removed from the soil by a cotton crop

From the number of cotton plants per acre a fair idea can be obtained regarding the total quantity of each mineral and nitrogen absorbed by a cotton crop from the soil. It is also possible to calculate the quantity of each mineral lost from the soil as a result of cropping for cotton, as that is the quantity which enters the seed cotton and the stems. The roots and the leaves generally remain in the soil and the minerals that are present in them are therefore returned back to the soil. The total quantities of different minerals and nitrogen absorbed by the cotton crops of the two varieties are given in Table II. A crop of American cotton of a stand of 9,000 plants per acre absorbs 100 lb. of potash and 75 lb. of lime more than a *desi* crop of 13,000 plants per acre. The soil gets depleted of 177 lb. of nitrogen, 190 lb. of potash and 40 lb. of phosphoric acid per acre when a crop of Americans is harvested, and of 192 lb. of nitrogen, 170 lb. of potash and 41 lb. of phosphoric acid when a crop of *desi* is harvested.

TABLE II

Quantities of different minerals and nitrogen in lb. absorbed and lost from the soil per acre (when yield of seed cotton is 15 mds. per acre)

Mineral	Total quantities absorbed		Total quantities lost	
	American	*Desi*	American	*Desi*
Nitrogen	288	283	177	192
P_2O_5	60	59	40	41
K_2O	353	250	190	177
CaO	384	308	90	113
MgO	75	85	42	43
SO_4	256	229	66	75
Cl_2	54	54	32	37
$Al_2O_3 + Fe_2O_3$	10	11	3	6

The losses of minerals and nitrogen from the soil in both cases are nearly equal. The loss of minerals and nitrogen to the soil will vary according to the stand, the yields of seed cotton per acre and properties of the soil where each crop is sown.

Mineral composition of different parts of the cotton plant

The quantities of minerals and nitrogen in different parts of the plant of the two varieties are given in Table III per plant basis and per 100 gm. of each part of the plant. The ash constituents are found in maximum amounts in the leaves of the two plants. This is due to the presence in leaves of largest amounts of lime and sulphur, which are required in small amounts for the formation of bolls, as judged from the amounts found in them. Nitrogen contents of the bolls and leaves are nearly the same in both the varieties. The leaves of the *desi* plants contain less potash than the bolls, while the potash is more concentrated in the leaves than in the bolls in the American plant. Similarly, the leaves of *desi* contain less potash and more sulphur and magnesia than the leaves of the American plant. These differences between lime, sulphur and potash contents in the two varieties have come out to be statistically significant. There are also some small differences in the contents of other minerals in the bolls and leaves of the two varieties as can be seen from Table III. For instance, the bolls of the *desi* plant contain slightly higher percentages of potash, magnesia and sulphur than the bolls of the American plant.

TABLE III

Quantities of minerals and nitrogen in gm. in different parts of the cotton plant

Variety	Plant part	Dry matter	Ash	N_2	K_2O	CaO	MgO	Al_2O_3 + Fe_2O_3	P_2O_5	SO_4	Cl_2
				Gm. per each plant part							
American . (24-12-35)	Root	31·6	0·99	0·17	0·37	0·20	0·07	0·01	0·04	0·10	0·09
,, .	Stem	319·5	12·75	2·31	4·60	2·92	0·98	0·05	0·54	1·64	0·78
,, .	Leaf	245·0	41·60	5·41	7·84	14·63	1·62	0·34	1·02	9·51	1·01
,, .	Bolls	268·5	14·13	6·62	5·12	1·62	1·12	0·10	1·42	1·71	0·84
Desi . . (26-11-35).	Root	28·5	0·97	0·13	0·31	0·26	0·07	0·01	0·03	0·08	0·08
,, .	Stem	153·5	6·54	0·96	1·43	2·10	0·49	0·03	0·15	0·60	0·42
,, .	Leaf	135·3	24·37	3·06	2·60	8·75	1·01	0·16	0·44	3·53	0·51
,, .	Bolls	234·8	13·93	5·11	5·22	1·91	1·21	0·17	1·20	1·90	1·06
				Gm. per 100 gm. of each plant part							
American . (24-12-35).	Root	100	3·14	0·56	1·17	0·63	0·23	0·04	0·13	0·33	0·28
,, .	Stem	100	3·99	0·72	1·41	0·91	0·31	0·02	0·17	0·51	0·24
,, .	Leaf	100	16·98	2·21	3·20	5·90	0·66	0·13	0·41	3·88	0·41
,, .	Bolls	100	5·27	2·47	1·91	0·61	0·42	0·04	0·53	0·64	0·31
Desi . (26-11-35)	Root	100	3·42	0·45	1·08	0·90	0·24	0·05	0·11	0·28	0·26
,, .	Stem	100	4·26	0·63	0·93	1·37	0·29	0·02	0·10	0·39	0·27
,, .	Leaf	100	18·01	2·26	1·92	6·47	0·75	0·11	0·32	4·83	0·38
,, .	Bolls	100	5·94	2·18	2·27	0·82	0·52	0·07	0·51	0·81	0·45

Composition of ash of the cotton plant

The percentage of each mineral in the ash of the plants of the two varieties was determined to see if there was any difference in the relative amount of the minerals that make up the ash of each plant. This method of expressing the results will indicate more correctly the differences in the mineral composition of the plants than the results calculated as percentages in dry weights. The ash of both the plants contains highest amounts of lime, potash and sulphates and the differences found in the contents of the three minerals in the two varieties, on percentage dry matter, are again seen on percentage ash basis.

TABLE IV

Percentage composition of ash of the cotton plant and of the different parts

Variety	K_2O	CaO	MgO	Al_2O_3 + Fe_2O_3	P_2O_5	SO_4	Cl_2
			Gm. per whole plant				
American . . .	25·75	27·85	5·46	0·71	4·34	18·65	3·92
Desi . . .	21·08	28·44	6·07	0·82	3·99	20·01	4·52
			Gm. for each part				
American—							
Root . . .	37·30	20·00	7·49	1·36	4·27	10·45	9·02
Stem . . .	35·35	22·89	7·69	0·44	4·21	12·83	6·14
Leaf . . .	18·35	35·10	3·89	0·78	2·41	22·85	2·44
Bolls . . .	36·25	11·52	7·93	0·70	10·15	12·12	5·94
Desi—							
Root . . .	31·58	26·43	6·93	1·43	3·13	8·37	7·66
Stem . . .	21·84	32·07	6·85	0·44	2·37	9·25	6·43
Leaf . . .	10·67	35·95	4·16	0·74	1·81	26·82	2·12
Bolls . . .	38·02	13·95	8·69	1·34	8·53	13·67	7·65

The ash of the stem, root and bolls contains largest amounts of potash, while the ash of the leaves contains largest amount of lime and sulphur. The ash of the roots and the stems of the *desi* plant is richer in lime than the ash of the same organs of the American plant, while the reverse relations hold good in case of potash, magnesia and phosphoric acid.

The potash and magnesia remain accumulated in the stems and lime and sulphur remain accumulated in the leaves. All minerals except lime, sulphur and aluminium and iron are found in larger proportions in the ash of the bolls than in the ash of the leaves.

Minor elements present in the cotton plant

Sodium, manganese, copper and zinc were determined in different parts of the cotton plant of the two varieties (Table V). Sodium was found to occur in largest quantity amongst the four minerals, while the leaves contained maximum quantities of each mineral except copper which is found more in the bolls than in the leaves. This is expected as copper is known to occur in largest amount in the embryo of the cotton seed [McHargue, 1926].

TABLE V

Minor elements present in the cotton plant (mg. per 100 gm. of dry weight)

Parts of the plant	Na_2O		MnO		CuO		ZnO	
	American	*Desi*	American	*Desi*	American	*Desi*	American	*Desi*
Root .	71	42	0·8	0·9	0·6	0·7	1·4	1·7
Stem .	98	43	1·1	1·4	1·1	1·2	3·5	3·7
Leaf .	181	127	6·2	7·1	1·9	1·8	4·2	4·7
Boll .	21	28	1·9	3·0	2·8	3·1	2·4	2·7

The vegetative parts of the American contain more sodium than those of the *desi* plant. On the other hand, the bolls of the *desi* plant contain more of these four minerals than the bolls of the American plant.

§2. *Uptake of minerals by the cotton plant*

Uptake of potash, nitrogen and phosphoric acid

The potash contents of the root, the stem and the leaf decrease per unit dry matter as the plant grows, indicating a greater increase in the dry weight of each part in proportion to the uptake of potash from the soil (Fig. 1A). The potash contents of the root and the stem show a greater decrease than that of the leaves. Important differences between the two varieties are seen

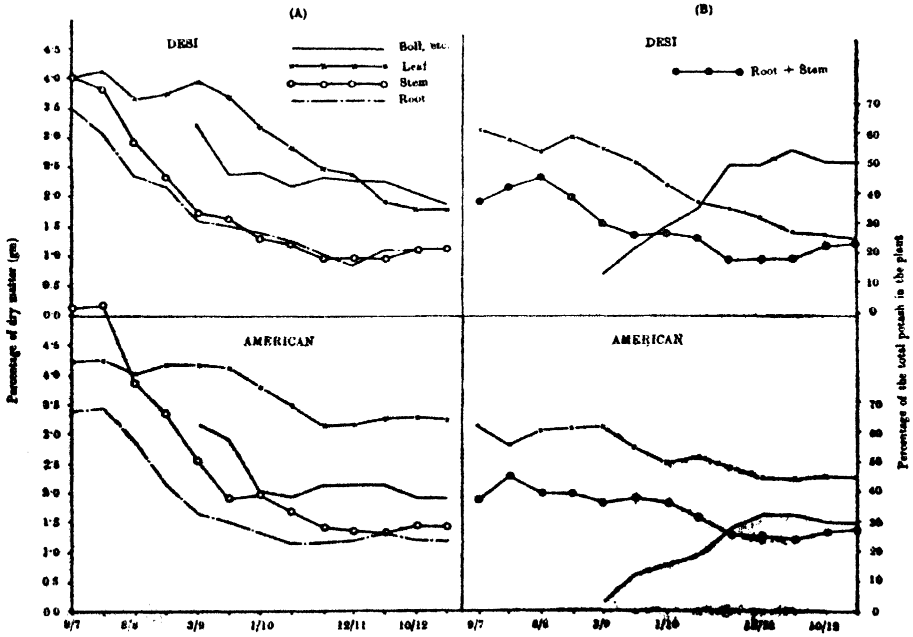

FIG. 1. (A) Potash in different parts ; (B) Distribution of potash in different parts

in the case of the leaves and the bolls.* The potash content of the leaves of the American plant does not show as marked a fall during the fruiting period as in the case of the leaves of the *desi* plant. The bolls of the *desi* contain at maturity more potash per unit dry matter than the leaves, while the leaves of the American plant contain more potash than the bolls at all stages. Thus the leaves of the *desi* get more depleted of potash than those of the American plant where it remains accumulated in the leaves.

The distribution of potash in different parts of the plant of the two varieties expressed as percentages of the total taken up by the plant shows similar features. The percentage of potash in the stem and root of the plant shows small decline in both cases. The amount of potash in leaves diminishes in the *desi* plant to a greater extent than in the leaves of the American plant. The most striking difference is in the bolls. The bolls of the *desi* plant contain at maturity 50 per cent of the total potash taken up by the plant, while the bolls of the American plant contain only 32 per cent of the potash found in the whole plant. This difference is partly caused by the greater percentage of dry matter of the bolls in the *desi* plant than that of the bolls of the American plant (Fig. 1B), and partly due to differences in the potash contents of the bolls in the two varieties (Table III).

The nitrogen contents of different parts of the plants of the two varieties show similar trends discussed above for the potash contents, with minor differences (Fig. 2A). The nitrogen in the stem and the root shows only a slight decline, while the decline in the nitrogen content of the leaves is

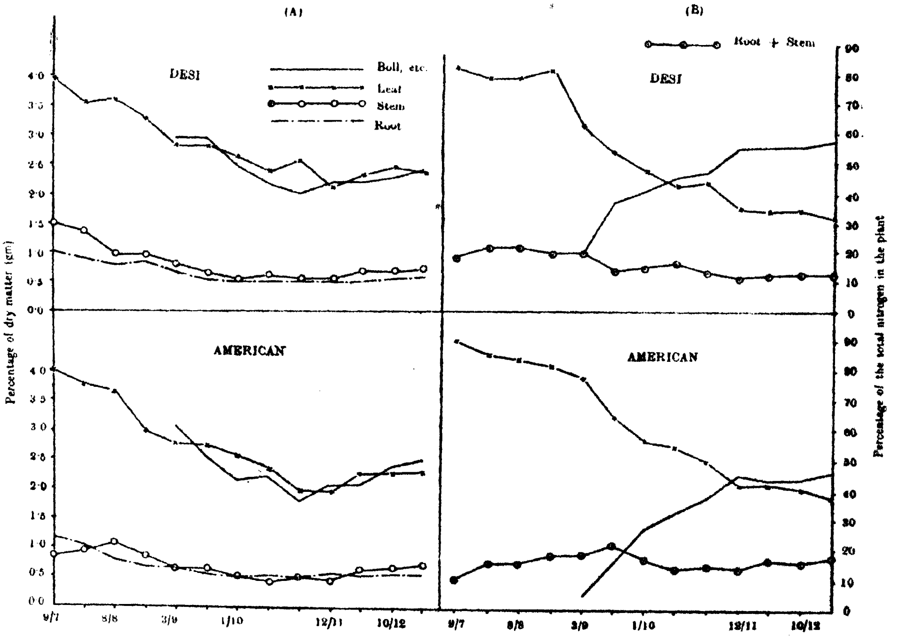

FIG. 2. (A) Nitrogrn in different parts ; (B) Distribution of nitrogen in different parts

great (from 4·0 per cent to 2·0 per cent). The mature bolls and leaves contain nearly equal quantities of nitrogen per unit dry matter. It will thus mean that potash migrates to the bolls from the stem and roots and partly from the leaves (more in the case of the *desi* plant than in the case of the American plant), while nitrogen mostly travels to the bolls from the leaves.

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*The term boll includes all buds, flowers and bolls produced on the plant up to the date of collection.

The percentage distribution of nitrogen in different parts of the plant supports the same conclusions. There is no change in the percentage distribution of nitrogen of the stem and roots at the bolling stage, while the percentage of nitrogen in the leaves falls from 90 per cent to 38 per cent in the American plant and 80 per cent to 30 per cent in the *desi* plant. The leaves and bolls of the American plant at maturity have nearly equal percentages of nitrogen distributed between them, while the bolls of the *desi* plant contain a greater proportion of total nitrogen than the leaves (Fig. 2B).

The changes in the phosphoric acid contents of different parts of the cotton plant are similar to those discussed above for nitrogen with one difference that the phosphoric acid contents of the bolls are higher than those of the leaves in both the varieties. The bolls of the American plant contain slightly more phosphoric acid than the bolls of the *desi* plant per unit dry matter, and these differences are found to be significant (Fig. 3A). But the percentage of phosphoric acid that enters the bolls of the *desi* plant is higher (65 per cent) than in the case of the bolls of the American plant (55 per cent) (Fig. 3B). The leaves of both the varieties are found to get depleted of its phosphoric acid at fruiting stage. There are greater differences in the percentage distribution of phosphoric acid between bolls and leaves in the case of the *desi* plant than what is found between the same organs of the American plant.

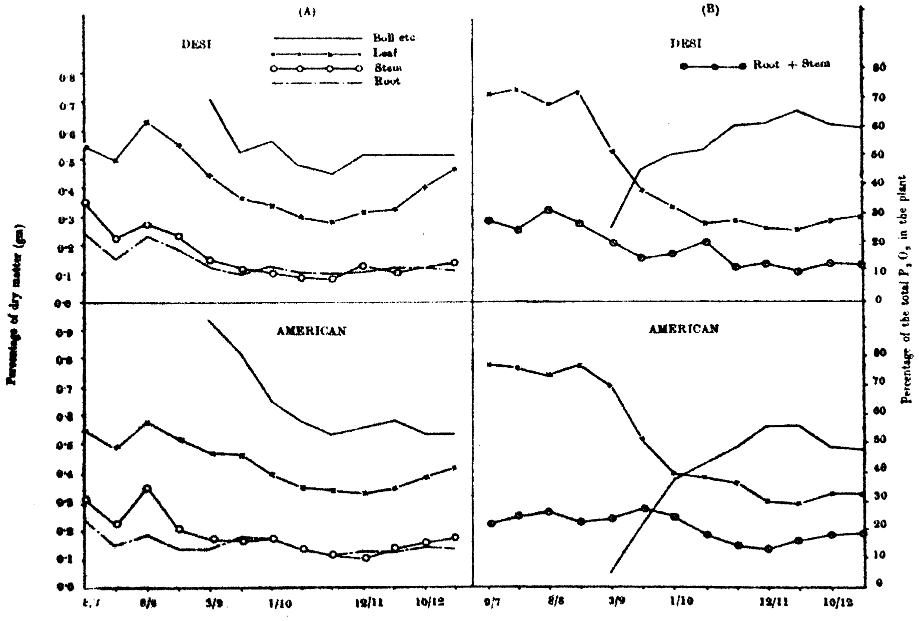

FIG. 3. (A) P_2O_5 in different parts ; (B) Distribution of P_2O_5 in different parts

The uptakes of these three important elements by the two varieties at different stages of growth and expressed as percentage of the total quantities taken up by each plant reveal interesting features. The maximum amounts of the three elements are taken up at the flowering to fruiting stage, i.e. middle of August to the end of September. The maximum is reached a fortnight earlier (15 September) in the case of the American plant than in the case of the *desi* plant (1 October) (Fig. 4A). The uptakes of the three elements appear to be more irregular in *desi* than in American, but the trend is almost the same in both the cases. There is negative uptake of potash in the *desi* plant and a secondary rise in the uptake of nitrogen and phosphoric acid in the American plant in November-December. In the case of the *desi* plant there is also an indication of a secondary rise in the uptake of the three elements at the end of October. Between 20 August and 30 September the American cotton plant takes up from the soil nearly 66 per cent of its total potash, 52 per cent of its total phosphoric acid and 45 per cent of its total nitrogen.

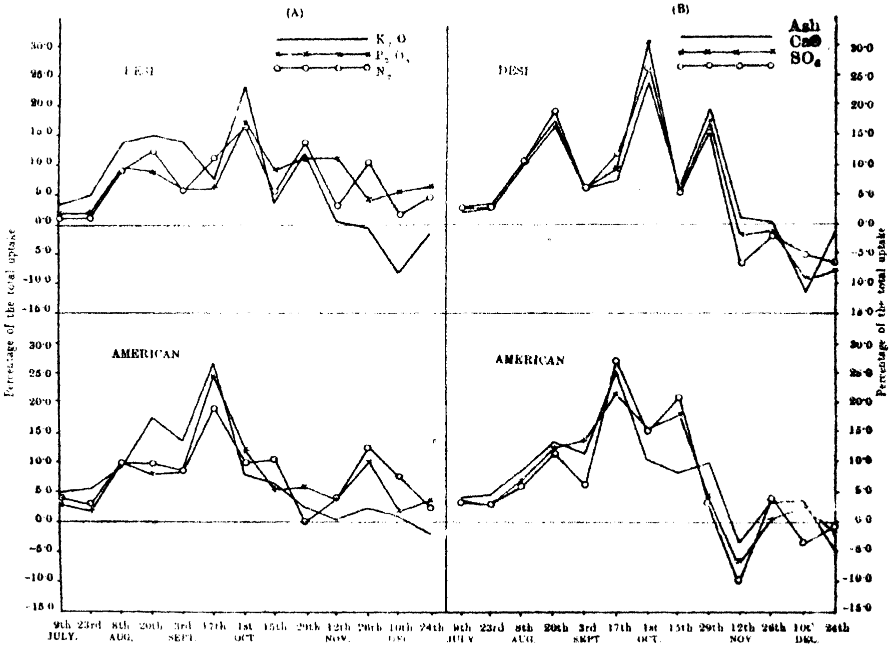

FIG. 4. Absolute uptake of minerals by American and *desi* cotton plants

Uptake of lime and magnesia

Lime contents of all the vegetative parts show very minor fluctuations at different stages of growth in both the varieties of cotton, indicating a continuous absorption of that mineral from the soil. The maximum amounts of lime are found in the leaves at all stages (Fig. 5A). There is very little migration of lime from the leaves to the fruiting parts as very small decrease in the percentage of lime in the leaves during the reproductive phase is visible (Fig. 5B). The percentage distribution of lime at all stages in the stem+roots also remains constant. The bolls of the *desi* plant contain slightly higher percentage of lime than the bolls of the American plant.

The uptake and distribution of magnesia in different parts of the plants differ in some respects from the uptake and distribution of lime. The magnesia contents of the roots and stems fall in the pre-flowering stage, while that of the leaves continue to fall in the flowering and fruiting stage as well. There is more magnesia per unit dry weight in the leaves than in the bolls (Fig. 6A). The great decline in the magnesia content of the leaves is also evident from the curve of percentage distribution of that mineral in the leaves of the two varieties. For the bolls it is a rising curve and for the leaves it is a falling curve, while the curve for the roots+stems shows only minor fluctuations (Fig. 6B). Thus the leaves are found to get depleted of its magnesia at the flowering-fruiting stage.

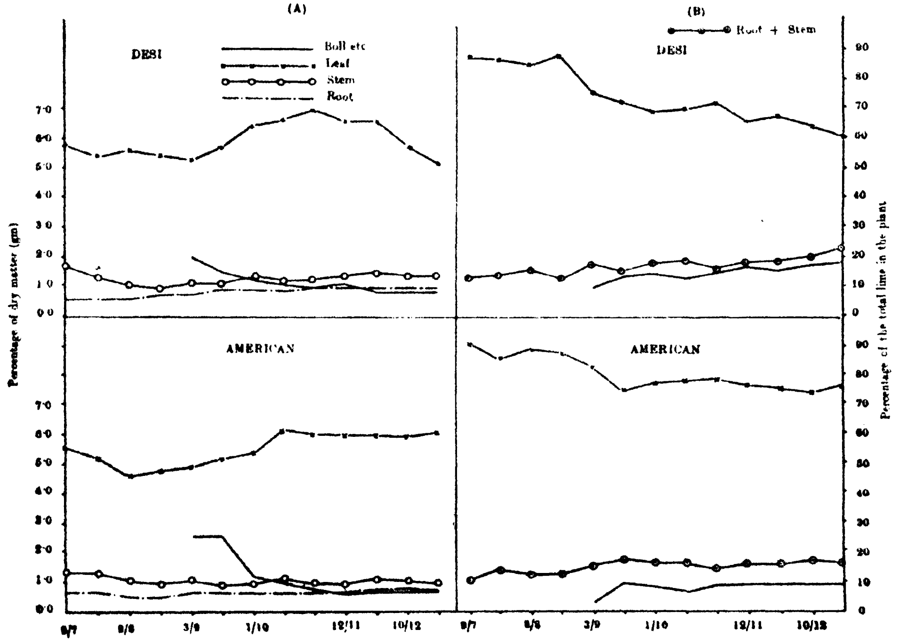

FIG. 5. (A) Lime in different parts ; (B) Distribution of lime in different parts

Maximum quantities of lime and magnesia are absorbed by the two varieties at the flowering stage, the peak of the maximum is reached a fortnight earlier in the case of the American plant than in the case of the *desi* plant (Figs. 4B and 7B). In the case of the *desi* plant secondary maximum in the uptake of lime is also found at the pre-flowering stage and at the fruiting stage, while these are not so pronounced in the case of the American plant. There is also negative absorption of lime in November in both the varieties after which a small and temporary rise in the uptake is again observed. The secondary maxima in case of magnesia are not pronounced in any variety though there is a decline in the absolute uptake with a rise again in November-December,

Uptake of iron and aluminium

Unlike other minerals the iron content of the roots is higher than that of the stems. The iron contents of the leaves, like lime and other minerals, are highest. There is a gradual fall in the iron content of the leaves, while the fluctuations in the same mineral in the roots and stems are less marked. The bolls of the *desi* plant contain greater amount of iron than the bolls of the American plant (Fig. 8A).

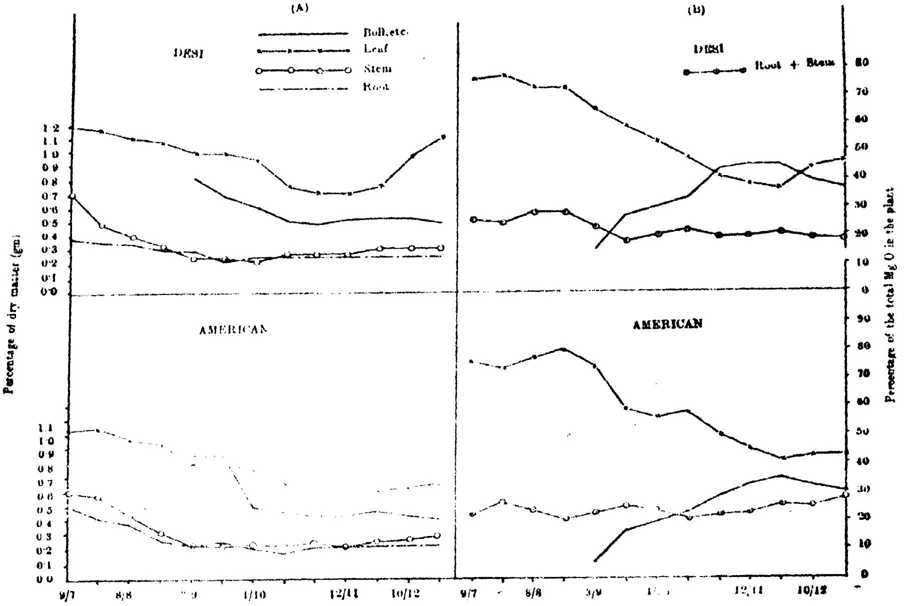

FIG. 6. (A) MgO in different parts ; (B) Distribution of MgO in different parts

The leaves show depletion of iron at the flowering-fruiting stage. The decline is greater in the case of *desi* than in the case of American (Fig. 8B). As a result, the iron content of the leaves of the American plant remains very high at maturity, indicating that like potash the leaves do not get depleted of this mineral. The bolls of the *desi* plant contain more iron (50 per cent of the total) than the bolls of the American plant (25 per cent of the total).

The trend in the uptake of aluminium in the two varieties is slightly different from that of iron. All parts show decreases in aluminium at pre-flowering stages, after which no further fall is evident (Fig. 9A). The percentage distribution of aluminium in different parts show the same features dicussed above for iron and they are therefore not stated here.

The absolute uptake of aluminium and iron at different stages of growth show some departures from the uptake of other minerals so far discussed (Fig. 7A). The maximum uptake as compared to other minerals occurs a month and a half earlier, i.e. in the pre-flowering stage, in the *desi* plant and a month earlier in the case of the American plant. The maximum is reached, unlike other minerals, earlier in the *desi* plant than in the American plant. The *desi* plant passes through another period of high uptake of these minerals during the fruiting phase. In both the varieties there is negative absorption of these minerals in the month of November with a small positive rise again in December in the American plant.

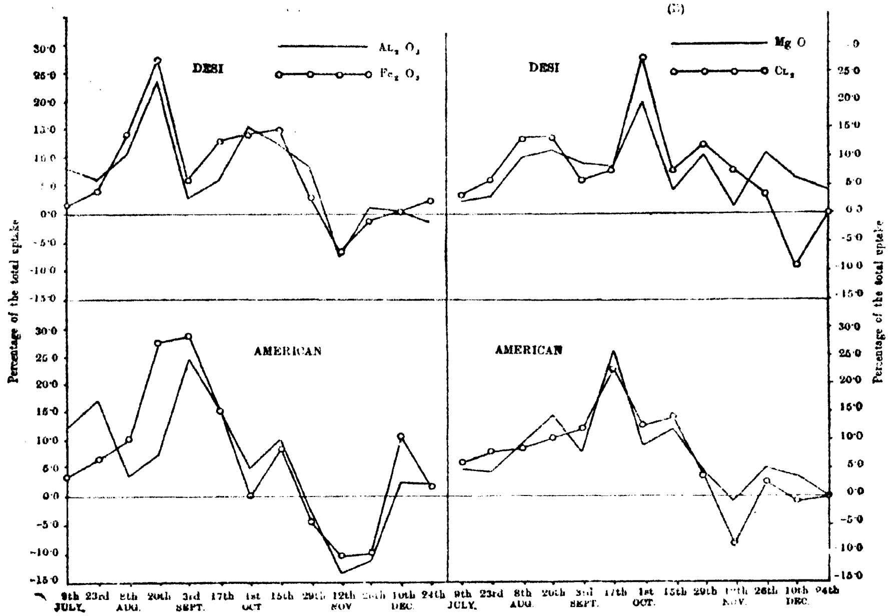

Fig. 7. Absolute uptake of minerals by American and *desi* cotton plants

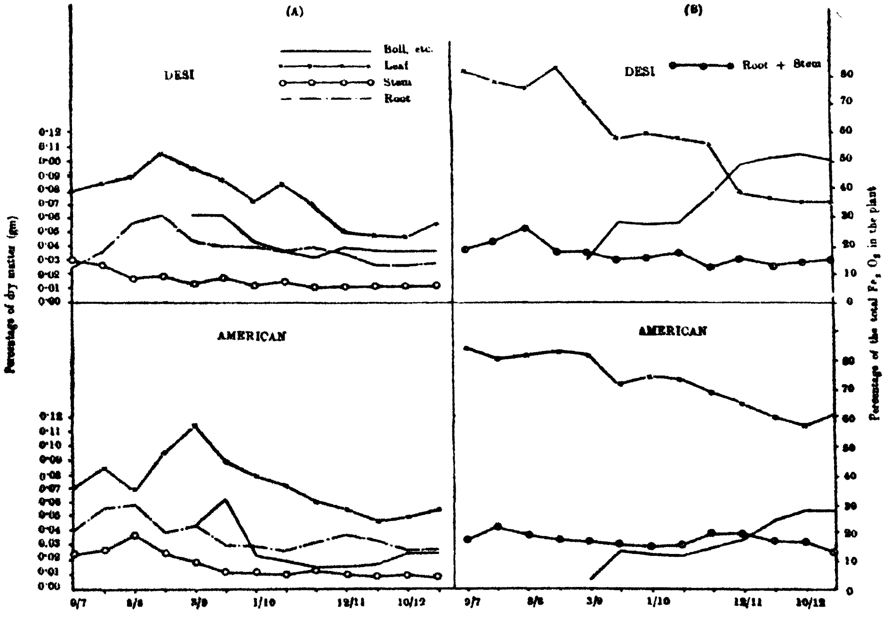

Fig. 8. (A) Fe$_2$O$_3$ in different parts; (B) Distribution of Fe$_2$O$_3$ in different parts

Uptake of sulphates and chlorides

The uptake and distribution of sulphates in the two varieties closely resemble the trends already discussed for the uptake and distribution of lime.

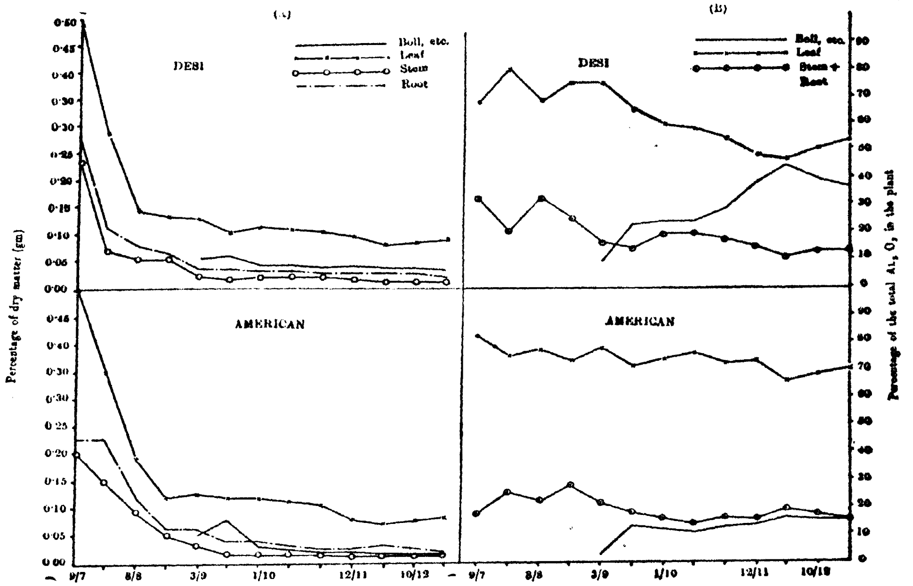

FIG. 9. (A) Percentage of Al_2O_3 in different parts of cotton plant ; (B) Distribution of Al_2O_3 in different parts

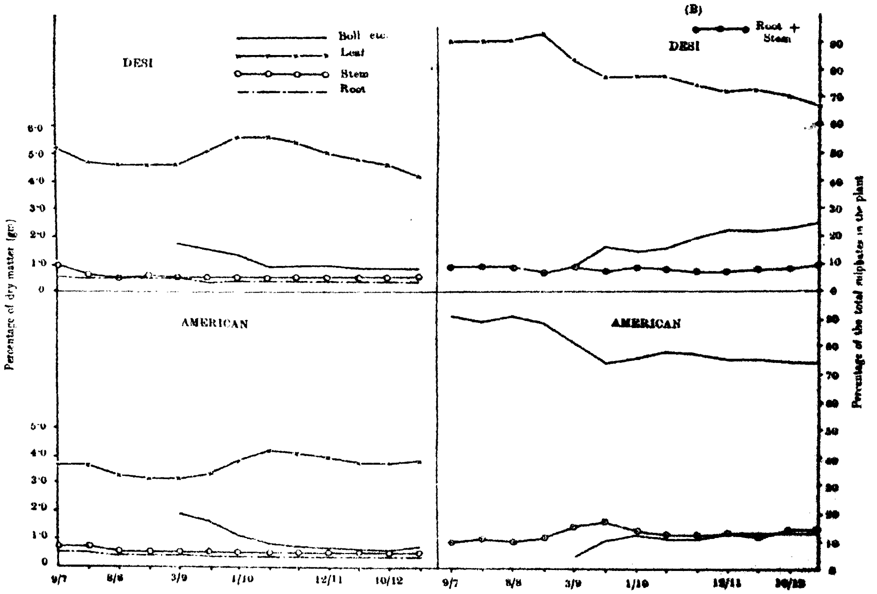

FIG. 10. (A) Percentage of sulphats in different parts ; (B) Distribution of sulphates in different parts

The close similarity between the two can be readily seen by studying the curves for lime and sulphates given in Figs. 5A and 10A. Sulphur remains accumulated in the leaves which contain 70-75 per cent of the total sulphates taken up by the *desi* or the American plant (Fig. 10B). Thus, like lime, there is very little migration of sulphur from the leaves to the fruiting parts. The percentage distribution of sulphates in the bolls of *desi* is higher than in the bolls of American.

The chloride contents, on the other hand, per unit dry weight, diminish as growth proceeds, in all the parts of the plant of the two varieties (Fig. 11A). Like magnesia, the curves for chlorides show steep falls in all the vegetative parts, in the pre-flowering stages. During the flowering-fruiting stages the decline in the chloride content of the leaves continues, while the decline is very small in the stems and the roots of the *desi* plant and it does not occur at all in the stems and the roots of the American plant (Fig. 11A). The relative distribution of this mineral in the different parts of the plant shows again the same features discussed for potash, magnesia, iron and aluminium (Fig. 11B). The chloride content of the leaves falls as it migrates to the bolls. In the case of *desi*, the bolls contain a greater percentage of chlorides than the leaves, while the reverse is the case in American variety.

The maximum uptakes of sulphates and chlorides occur during the flowering stage ; the peak of the maximum is reached a fortnight earlier in the American plant than in the *desi* plant (Figs. 4B and 7B). The curve for sulphates follows the same trend as the curve for lime, and the curve for chlorides shows the same trend as the curve for magnesia. The negative absorption of chlorides occurs a fortnight earlier in the American plant than in the case of the *desi* plant, while this is not the case with sulphates in the two varieties.

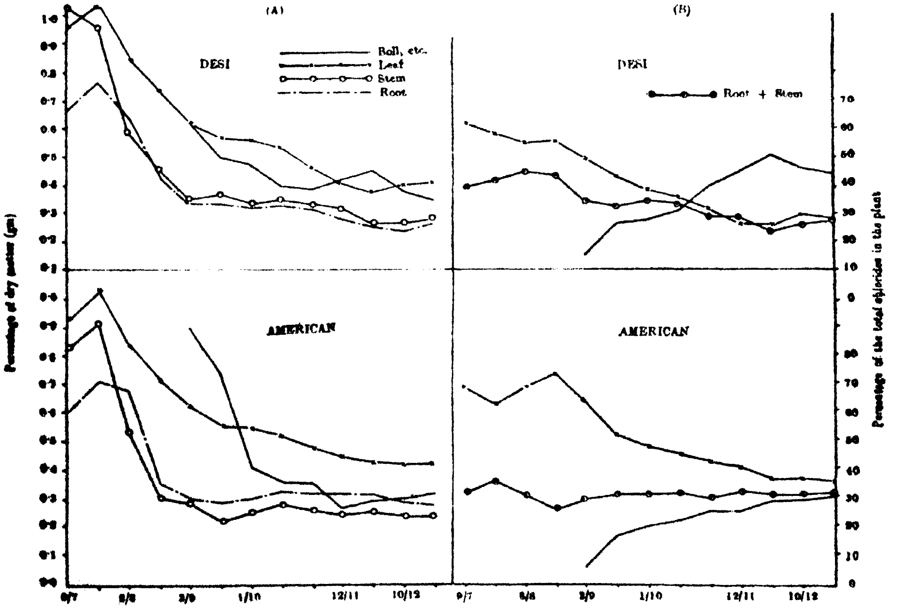

FIG. 11. (A) Percentage of chlorides in different parts of cotton plant ; (B) Distribution of chlorides in different parts

Uptake of total ash constituents

If all the minerals composing the silica-free ash of the two varieties are taken together, it is noticed that they follow the same trend in the uptake and distribution in the different parts as the minerals like lime and sulphates in the two varieties and potash also in the case of the American plant. This is due to the greater proportions of lime and sulphates present in the ash of the plant in relation to other minerals. The total ash shows a decline in the stem and the roots in the pre-flowering stage, but this was not the case with lime or sulphates.

The curves for the absolute percentage uptake of ash constituents per plant show the same trends as the curves for lime or sulphates (Fig. 4B).

Relative rates of uptake of minerals in the two varieties

The relative rates of the uptake of different minerals were calculated by the formula stated before in order to see if there were any differences in the relative rates of uptake of the minerals between the two varieties. The curves show that the relative rate of uptake in each case for each mineral falls with time like the relative growth rate (Fig. 12A). There is an indication of higher relative rates of uptake of potash, nitrogen, lime, and phosphoric acid in the early stages in the American plant than in the case of the *desi* plant. No differences are noticed between the two varieties in the relative rates of uptake of the remaining minerals.

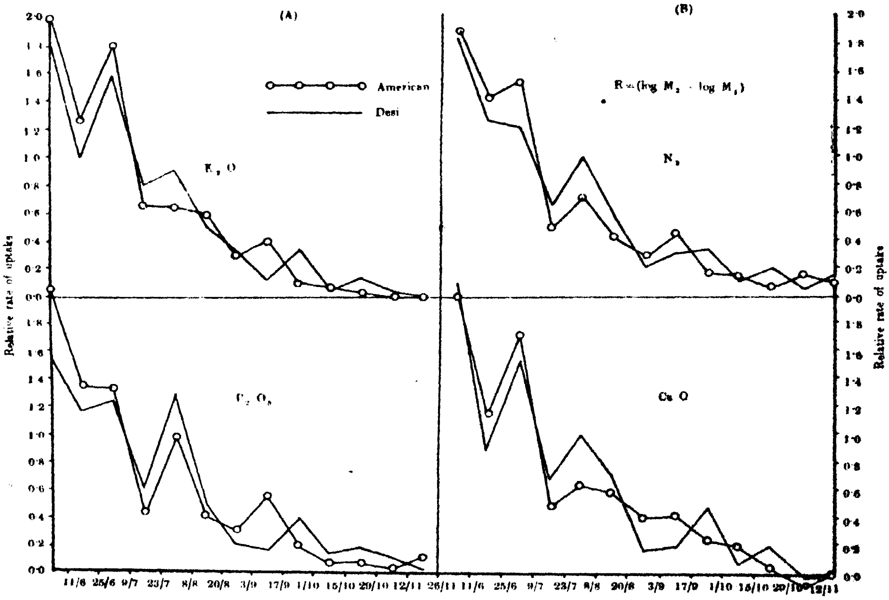

FIG. 12. Relative rates of uptake of different minerals and nitrogen

Increase and distribution of dry matter and moisture in different parts

The present study will not be complete without determining the increase and distribution of the dry matter in different parts of the plant of the two varieties. The maximum amounts of dry matter per plant are found in the bolls in the *desi* plant and in the stems in the American plant. The graphs (Fig. 13B) showing percentage distribution of dry matter in different parts of the plant show that the *desi* plant produces more boll material than the American plant in proportion to their total dry weights. The American plant has greater percentage of dry matter in the stems than in the bolls. Thus,

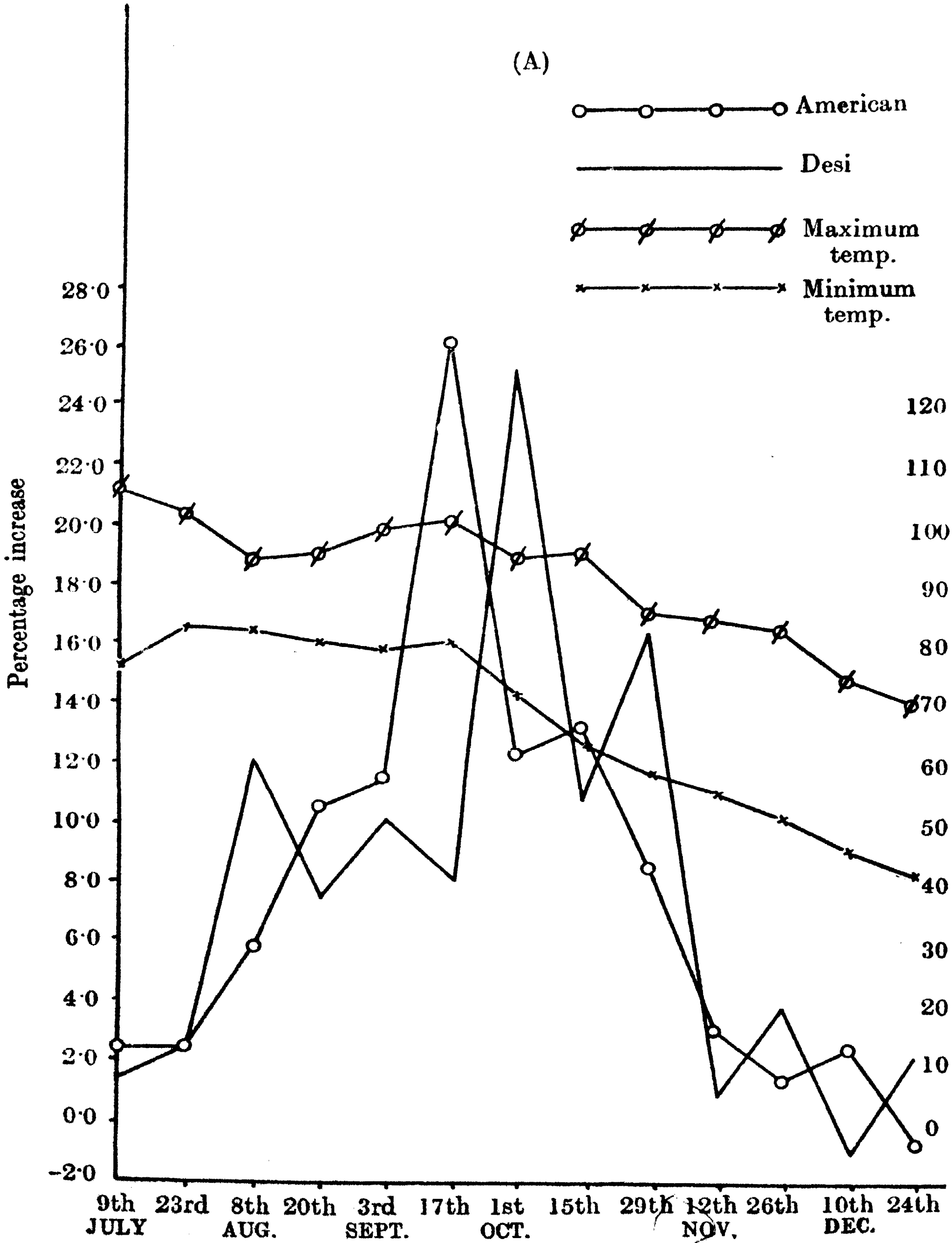

FIG. 13 (A). Percentage increase in the dry weight of plant at fortnightly intervals of American and *desi* cotton

the *desi* plant appears to be more efficient in boll production than the American plant (Fig. 13B).

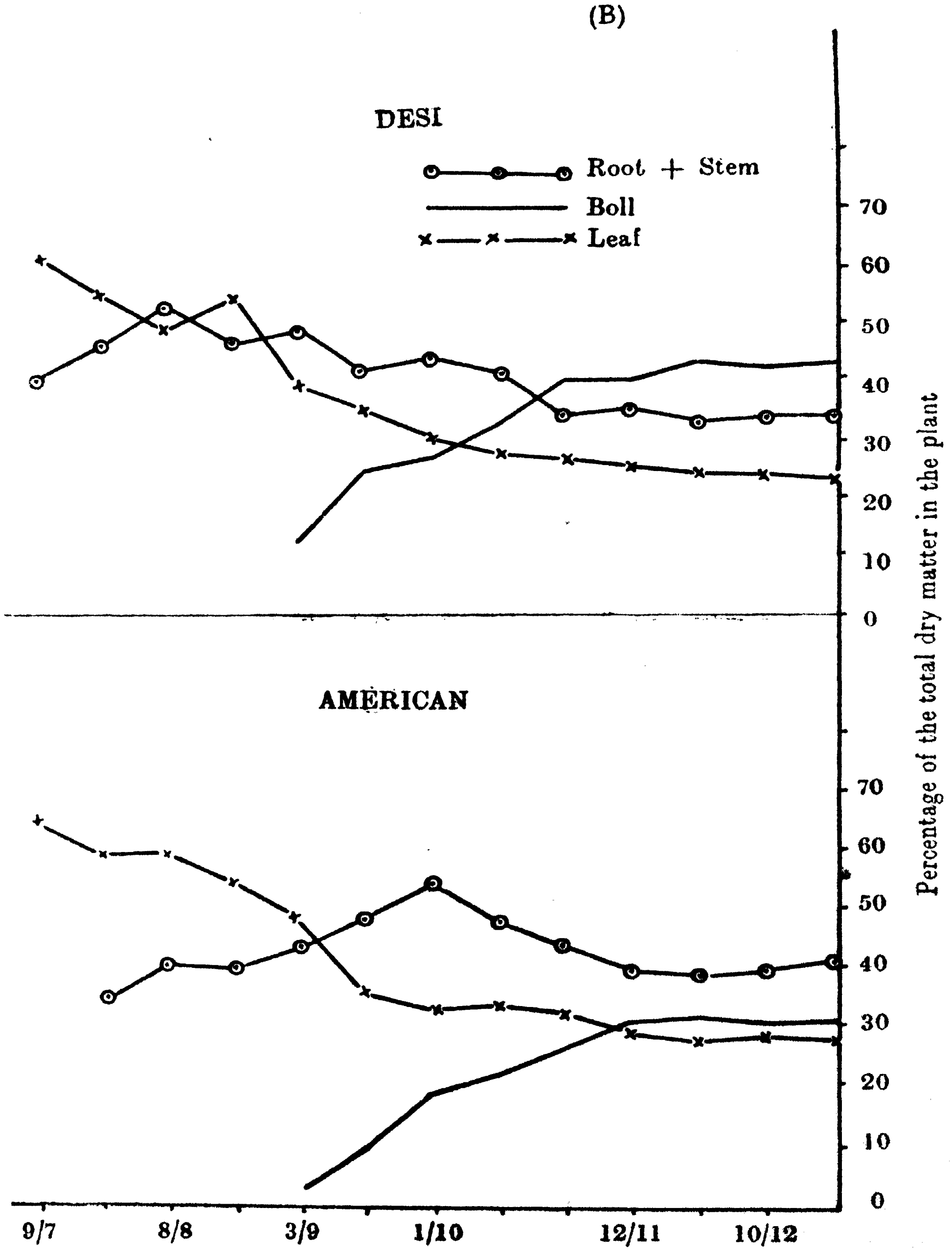

FIG. 13 (B). Percentage of dry matter in different parts

The percentage increase in the dry weight reaches its maximum in September in the case of the American plant and a fortnight later in the case of the *desi* plant (Fig. 13A). The maxima of the percentage increase in dry weights thus coincide with the maxima of the mineral uptake in the two varieties (except for iron and aluminium).

The moisture contents of the roots, stems, leaves and the bolls were calculated as percentages of dry matter in each case. The leaves and bolls are found to contain the highest amounts of moisture in both the varieties. The American plant contains more moisture in all its parts than the *desi* plant. It is a known fact that the fleshiness in plants is accompanied by a high potash content, while the plants that contain high calcium are generally more woody and contain less moisture. The differences in the moisture contents of the two varieties can therefore be correlated to the differences in their potash and lime contents.

CONCLUSIONS

Lime, potash and sulphates comprise nearly 70 per cent of the ash constituents that enter the cotton plant in the Punjab. Lime and sulphates enter the leaves in the largest amounts and remain accumulated there till senescence. The case of potash is different. The bolls contain more potash than the leaves in the *desi* plant, while the leaves contain more potash than the bolls in the case of the American plant.

At the time of fruiting the potash gets depleted from the stems, roots and leaves, while nitrogen and phosphoric acid get depleted mostly from the leaves. Thus the demand of the bolls for potash is met from all the vegetative parts of the plant, while the demand for nitrogen and phosphoric acid is met from the leaves only, with one difference that the depletion of potash from the leaves in the American plant is very little as compared with the *desi* plant. Lime and sulphates remain in the leaves at the time of fruiting, while no decrease in these minerals is also evident in the stem or the roots. Thus the bolls may be getting these minerals directly from the soil on account of their continued absorption from the soil.

It is also evident that magnesia travels from the leaves to the bolls at maturity and the same is the case with iron. On the other hand, aluminium gets depleted from all the parts and travel to the fruiting parts. Absorption of this mineral appears to fall off considerably in the pre-flowering stages as can be seen from the falls in the aluminium content of the leaves, roots and stems at that stage. The chlorides are found to behave like aluminium.

Thus, the demands of the bolls for lime and sulphates are met with from the soil, of potash mostly from the stems and roots and partly from the leaves, and of nitrogen, phosphoric acid, magnesia and iron mostly from the leaves alone, and of aluminium and chlorides from all the vegetative parts.

Maximum quantities of these minerals are absorbed by the two varieties at the flowering stages, the maximum point lying one stage earlier in the American plant than in the *desi* plant. The above conclusions hold good for both the varieties of cotton.

The distribution of different minerals and nitrogen in different parts of the cotton plant expressed as percentage of the total uptake of each reveals important differences between the two varieties. As a rule the leaves of the *desi* plants get depleted of their minerals more than the leaves of the American plant. Side by side the same minerals are found to enter the bolls of the *desi* plant in greater amounts than in the bolls of the American plant. As for instance, the fall in the potash content of the leaves in *desi* is greater than in the American plant, resulting in a greater quantity of the same element appearing in the bolls of the former than in the bolls of the latter, so much so that the bolls of a *desi* plant contain more than 50 per cent of the total potash, while the bolls of the American plant contain only 32 per cent of the total potash present in the plant. Similar difference, though to a smaller degree, is seen in the case of nitrogen and phosphoric acid. Iron and aluminium reveal the same difference in the two varieties. The bolls of *desi* plant contain about 40 per cent of total aluminium and 50 per cent of total iron as compared with 15 per cent and 35 per cent of the two minerals in the bolls of the American. Chlorides also enter the bolls of the *desi* plant in a greater proportion than in the bolls of the American plant. Magnesia again shows the same behaviour. Thus, more of these minerals migrate to the bolls in the case of the *desi* plant than in the case of the American plant, where these minerals remain accumulated in the leaves.

The differences can be explained or interpreted in two ways. The *desi* plant produces more boll material than the American plant in proportion to their total dry weights, and the greater percentages of these minerals that are found in the bolls of the *desi* plant may be due to greater percentage boll production in that variety. The second explanation is that translocation of these minerals in the American plant is in some way interrupted. This interference in the migration of ions to the fruiting parts may be primarily caused by the relative deficiency of any one or more of the minerals. Thus the greater accumulation of these minerals in the leaves of the American plant as compared to the *desi* plant may either be due to low efficiency of the former for boll production or to some interference in their conduction to the bolls. The accumulation of potassium and other minerals in the leaves of the American plant may also be due to some physiological causes.

The above-mentioned fact regarding the accumulation of minerals in the leaves of the American plants at maturity as compared to the *desi* plant is of importance in understanding the mineral matabolism of the *tirak* plants. This will be discussed in another contribution on the subject.

SUMMARY

The mineral composition of the different parts of the Punjab-American (4F) and *desi* (Mollisoni) cotton plants at fortnightly intervals is determined with an ultimate object of determining the nature of nutritional disorder that sets in the American plants when they suffer from *tirak* disease in the Punjab.

The quantities of different minerals in the American plant are as under, on percentage dry matter ; 2·2 gm. of CaO, 2·1 gm. of K_2O, 1·7 gm. of N_2, 1·5 gm. of SO_4, 0·35 gm. of P_2O_5, 0·44 gm. of MgO, 0·32 gm. of Cl_2 and 0·06 gm. of $Al_2O_3+Fe_2O_3$. The mineral composition of the *desi* plant is the same except that there is less of K_2O (1·7 gm.) and more of CaO (2·4 gm.) and SO_4 (1·7 gm.) in this variety as compared with the American plant.

The percentage composition of ash of the two varieties shows the same differences as stated above.

Leaves and bolls contain largest amounts of all minerals. The leaves contain more potash than the bolls in the American, while reverse is the case in the *desi* variety. The mineral contents of the bolls of the *desi* plants are higher than the mineral contents of the bolls of the American plant.

Percentages of lime and sulphates in dry matter of the roots, stems and leaves remain nearly constant in both the varieties at all stages of growth. Nitrogen, phosphoric acid and iron contents of the leaves diminish, while potash diminishes more in the stem and root than in the leaves. The remaining minerals fall in all the parts as the plant matures. Thus the demand of the bolls for lime and sulphates appear to be met directly from the soil, and for potash, it is met mostly from the stems and roots and partly from the leaves in the *desi* plant only. Nitrogen, phosphoric acid and iron travel to the bolls from the leaves, and the remaining minerals from all parts of the plant to the bolls.

The maximum uptake of all minerals occurs at the flowering stages in both the varieties, the peak of the maximum being reached by the middle of September in American and by the end of September in *desi*. This is the period when the maximum increases in the dry weights of the plants are also found to occur in both the varieties.

The study of the distribution of minerals and nitrogen in different parts of the plant shows that the bolls of the *desi* plant contain more of each mineral than the leaves, while the leaves of the American plant at maturity contains greater percentages of the total minerals than the bolls. Thus, the important minerals like potash, magnesia, phosphoric acid, iron and aluminium and chlorides remain accumulated in the leaves of the American plant. This is not so in the *desi* plant. This difference between the two varieties may be due to the greater percentage of dry matter of the bolls per plant in *desi* than in American.

The case with nitrogen is different. The concentrations of nitrogen in the bolls and leaves in the two varieties are nearly the same. The percentages of total nitrogen in the leaves of the two varieties at maturity are also equal. These facts have a bearing, as will be shown later, on the *tirak* disease of the American cotton plant.

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REFERENCES

Armstrong, G. M. and Albert, W. B, (1931). *J. Agric. Res.* **42**, 689—703

Fraps, G. S. (1919). *Texas Agric. Exp. Sta. Bull.* No. **247**

Gregory, F. G. (1926) *Ann. Bot* **40**, 1—26

Holley, K. T.; Pickett, T. A. and Dulin, T. G. (1931). *Ga. Agric. Exp. Sta. Bull.* No. **169**

Hutchinson, W. L. and Patterson, L. G. (1892). *Missi. Agric. Exp. Sta. Tech. Bull.* No. **1**

Kundrin, S. A. (1929). *Chem. Abst.* **23**, 4998

McHargue, J. S. (1926). *J. Amer. Soc. Agron.* **18**, 1076—83

Methods of Analysis of the Association of the Official Agricultural Chemists (1935). Fourt edition

Murphy, H. F. (1936). *J. Amer. Soc. Agron.* **28**, 52—7

Sutton, F. (1935). *Systematic hand-book of volumetric analysis*, 12th edition : J. & A. Churchill Ltd, London

White, H. C. (1914-15). *Ga. Agric. Exp. Sta. Bull.* Nos. **108**, **114**

*STUDIES ON THE PERIODIC PARTIAL FAILURES OF PUNJAB-AMERICAN COTTONS IN THE PUNJAB

IV. RELATION BETWEEN NITROGEN DEFICIENCY AND ACCUMULATION OF TANNINS IN LEAVES

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(With Plate XIII)

IN a previous contribution by the author [Dastur, 1939], it was shown that accumulation of a substance, belonging to the group of substances known as tannins, occurred in leaves of the 4F Punjab-American plants which later exhibited the symptoms of *tirak*, viz. premature yellowing and shedding of the leaves and cracking of the bolls which contain immature seeds and weak fibre. The accumulation of tannins was observed under the microscope as previously described in detail.

During the cotton season of 1937-38, the leaves of 4F cotton plants from a manurial experiment laid out in Square 32B of the Lyallpur Agricultural Farm were examined periodically for tannins from the month of July onwards. The manures used were all combinations of ammonium sulphate, potash and superphosphates. Control plots also were included. Microscopic examinations of four leaves of each of five plants under each treatment were made separately at about fortnightly intervals. The result of this investigation showed that there was a great accumulation of tannins in the leaves of plants grown on the control plots and on plots that had been manured with potash or phosphoric acid, while there was little or no accumulation of tannins in the leaves of plants on plots that had received ammonium sulphate, either singly or in combination with potash or superphosphate or both. In fact in many of the latter cases the leaves were found to be free from tannins. In plots to which no nitrogen had been applied the tannins were found to accumulate from the third week of August onwards. There was thus internally a marked difference between leaves of plants from nitrogen and no-nitrogen plots.

The leaves of plants from no-nitrogen plots also showed a great accumulation of starch in the palisade and spongy cells. The leaves collected at dawn showed the chloroplasts filled with starch grains which in many cases had ruptured the chloroplasts, as described previously [Dastur, 1939]. The leaves of plants from nitrogen plots were, on the other hand, either free from starch or contained only very small amounts.

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The results stated above suggested some relationship between starch and tannin accumulations in leaves and their nitrogen contents. This possible relationship was, therefore, investigated during the next cotton season.

INVESTIGATION

In the cotton season of 1938-39, two manurial experiments were laid out in Square 32D of Lyallpur Agricultural Farm. In the first experiment, 50 lb. of nitrogen in the form of ammonium sulphate was applied either: (1) at sowing time, (2) at flowering time, or (3) at both stages. Control plots were also included. In a second experiment in the same square (1) sulphate of ammonia and (2) green manuring were among the treatments. The leaves of plants from the nitrogen and no-nitrogen plots in both experiments were tested for tannins as described below.

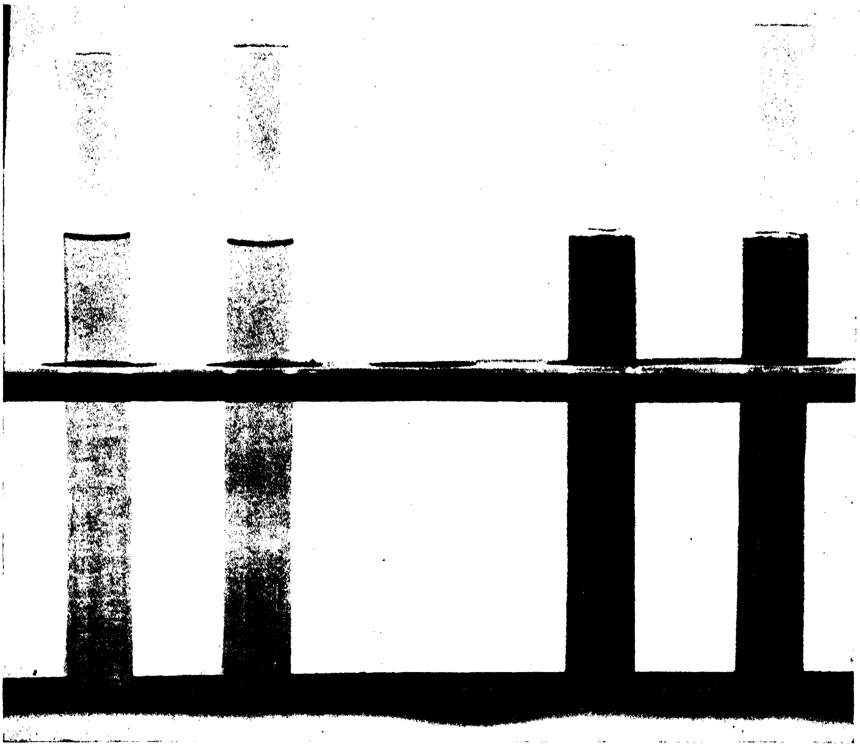
A leaf punch was used to cut out a circular area from a leaf. Such circular discs were cut out from four leaves at four nodes from each plant, each sample consisting of five plants selected at random. Thus, the total number and area of leaf-discs and the number and position of the nodes from which they were taken were kept constant. These tests were done in duplicate.

The leaf-discs were extracted with 25 c. c. of water for two hours in a water-bath kept at about 80°C. The extract was then filtered. The *p*H of the extract generally varied from 5·2 to 5·5. To 10 c. c. of the extract 2 c. c. of 0·02 per cent osmic acid was added. If tannins were present a black tinge in the colour of the extract was produced; otherwise, there was no change in the colour of the extract.

It may be pointed out in passing that the *p*H of the leaf extract bears a great relation to the development of the colour on adding osmic acid, if tannins are present. If the extract is made more acidic by the addition of an acid, a blue-green or greenish brown colour is produced within half an hour on adding osmic acid. If the extract is made alkaline by the addition of an alkali, a deep yellow to orange-red colour is produced. If tannins are not present in the extract, its colour does not change when osmic acid is added. In the tests for tannins which were carried out in this investigation the leaf extract was not acidified and a black tinge in the extract produced on the addition of osmic acid was taken as a positive test for tannin. If a blackish tinge in the colour of the extract did not develop, it was taken as a negative test for tannins (Plate XIII). The method described above is more rapid and time saving than the microscopic method of testing for tannins employed previously [Dastur, 1939].

The results of the tannin tests made in the plots of the two field experiments in this investigation are given in Table I.

The positive tannin test from plants grown in plots to which no nitrogen had been applied was not given by leaves till September. The results again showed that accumulation of tannins in leaves did not occur in plots treated with nitrogenous fertilizers. It was also again confirmed that inorganic fertilizers, like potash or superphosphate, had no effect on the accumulation of tannins in leaves as tannins were again found to be present in the leaves in plots treated with these fertilizers.



Negative (left) and positive (right) tests for tannins in the extracts of leaves with a high (3·53 per cent) and a low (2·14 per cent) nitrogen contents

TABLE I

Effect of nitrogenous fertilizers on the accumulation of tannins in leaves (Two replicates)

Treatment	Dates				
	9-9-38	21-9-38	29-9-38	7-10-38	20-10-38
Control	+ +	+ +	+ +	+ +	+ +
Green manure . . .	— —	— —	— —	— —	— —
50 lb. N as sulphate of ammonia at sowing	— —	— —	— —	— —	+ +
50 lb. N as sulphate of ammonia at sowing	— —	— —	— —	— —	+ +
50 lb. N as sulphate of ammonia at flowering	— —	— —	— —	— —	+ +
50 lb. N at sowing + 50 lb. N at flowering as sulphate of ammonia	— —	— —	— —	— —	— —

It was evident from the results stated above that the nitrogen metabolism of the plant had some relation with the accumulation of tannins in leaves. Steps were, therefore, taken to determine the nitrogen content of leaves of plants grown in the control plots and also in plots treated with sulphate of ammonia in the first field experiment.

Leaves of five plants from each plot in the first field experiment were collected and dried for determination of total nitrogen by Kjeldahl's method. Samples of leaves were collected in August, September and October at about fortnightly intervals. The same leaf material, which was used for the determination of total nitrogen, was also tested for tannins. It was found that it made no difference in the tannin test whether the leaf material was dry or fresh. The results of these determinations are given in Table II.

The total nitrogen content of the leaves of plants from the control plots was found to be at a lower level than the similar content of the leaves of plants of the same stage from plots that had received ammonium sulphate in August. There was thus an increased absorption of nitrogen by plants treated with the fertilizer as compared with the control plots. The total nitrogen of the leaves of the control plots fell to 1·76 per cent of the dry matter on 22 September, while it was maintained at a higher level in the leaves of plants from the manured plots, and varied from 2·5 to 3·1 per cent. This difference between the control and treated plots was also found in leaves collected in October.

TABLE II

Total nitrogen content of the leaves giving positive and negative tests for tannin

Plot No.	26 August 1938		20 September 1938		20 October 1938		Wt of seed cotton per boll in gm.	Yield in lb. per plot
	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin		
				Controls				
1	2·58	—	1·82	+	1·46	+	1·56	15·8
4	2·99	—	2·26	+	1·62	+	1·55	13·1
16	2·54	—	1·71	+	1·57	+	2·06	15·6
20	2·82	—	1·65	+	1·22	+	1·85	18·8
39	1·97	+	1·51	+	1·23	+	1·61	16·6
50	2·42	+	1·71	+	1·15	+	1·84	16·3
62	2·52	—	1·71	+	1·31	+	1·31	15·4
Mean	2·55		1·76		1·36		1·68	15·9
			50 lb. nitrogen at sowing time (16 May)					
18	3·34	—	3·15	—	2·32	+	2·15	31·0
13	3·22	—	2·81	—	2·31	+	1·83	25·6
49	*		2·65	—	1·85	+	2·44	35·5
32	2·69	—	2·20	+	1·75	+	2·16	36·2
45	*		2·69	—	1·70	+	2·21	32·3
59	3·46	—	2·67	—	1·98	+	2·36	31·0
52	2·98	—	2·66	+	2·03	+	2·22	32·6
64	3·27	—	2·85	—	2·01	+	2·31	35·3
Mean	3·16		2·71		1·99		2·21	33·4
			50 lb. nitrogen at flowering (17 August)					
8	2·96	—	2·43	+	2·07	+	1·86	25·3
19	2·69	—	2·63	+	2·00	+	1·96	27·4
26	2·69	—	2·74	—	2·30	+	2·47	34·0
38	2·27	—	2·52	—	1·81	+	2·16	31·4
37	2·55	—	2·41	+	1·47	+	1·98	31·8
53	2·51	—	2·46	+	1·84	+	2·26	29·3
63	2·94	—	2·74	—	2·01	+	2·55	32·3
58	3·01	—	2·63	—	1·79	+	2·15	29·3
Mean	2·70		2·57		1·91		2·17	30·1
			50 lb. of nitrogen at sowing + 50 lb. of nitrogen at flowering					
28	2·71	—	3·24	—	2·68	—	2·52	8·8
15	3·18	—	3·24	—	2·77	—	2·04	25·7
42	2·98	—	3·04	—	2·51	—	2·29	37·9
57	3·28	—	2·97	—	2·38	—	2·50	34·5
60	3·15	—	3·21	—	2·40	+	2·44	39·9
40	*		3·21	—	2·38	+	2·52	37·6
56	3·17	—	2·96	—	2·40	+	2·32	39·9
35	3·32	—	3·10	—	2·42	+	2·34	37·4
Mean	3·11		3·11		2·49		2·37	36·4

* Sample missing

The positive test for tannin was given by the leaves when the total nitrogen of the leaves fell in the neighbourhood of 2·5 per cent, while the test was negative when total nitrogen of the leaves was higher than 2·5 per cent. The leaves of the control plots gave a positive tannin test early in September, and this was accompanied by a low nitrogen level of the leaves. The negative test was generally accompanied by a high nitrogen level of the leaves. The values of total nitrogen in leaves giving a positive test were slightly higher than 2·5 per cent in two determinations, as seen from Table II, but such results are not unexpected as the leaf material is composed of all leaves, young and old, from five plants from the field. If the leaves of one of the five plants contain tannins with low nitrogen content, and if the leaves of the remaining four plants contain high nitrogen and no tannins, then the tannin test, which is a colour reaction, may be given but the average value of total nitrogen may come out higher than 2·6 per cent. This happens only in plots manured with sulphate of ammonia. The manure may not reach some plants on account of ununiform spreading of the fertilizer.

The nitrogen content of the leaves giving a negative test was found to be significantly higher than the nitrogen content of leaves giving a positive test for tannins.

Examination of sections of leaves under a microscope in the cotton season of 1937-38 showed that the accumulations of starch in the mesophyll cells occurred before the tannins were found. It was also observed that there was very little accumulation of starch in leaves from nitrogen plots, while starch and tannins were found in considerable amounts in the leaves of no-nitrogen plots. The starch content of the leaves from some of the plots of the first field experiment of 1938-39 was, therefore, examined, and it was found that while the starch content of leaves of plants manured with sulphate of ammonia was negligible, the starch content of leaves from manured plots varied from 2 to 6 per cent.

It is possible that starch accumulation in leaves occurs as a result of deficiency of nitrogen, when the carbohydrates synthesized in leaves are not as rapidly utilized for the synthesis of proteins. The surplus of carbohydrates that remains unutilized is stored as starch. It is also possible that the tannins are formed from carbohydrates. The tannin deposits and starch grains were found to occur in the same cell in the tissues of the leaves [Dastur, 1939]. In many cases tannins were seen covering the starch grains, both in the leaves and in the roots.

Accumulations of starch and tannins in leaves may not be the direct result of nitrogen deficiency, but may be due to deficiency of other minerals which are not absorbed by the plant in required amounts as a result of shortage of nitrates in the soils. It is a well-known fact that the absorption of one ion is governed, amongst many other factors, by the availability and absorption of another ion. When nitrogen is added to the soil, other ions may be absorbed in increasing proportions, thus resulting in the non-accumulation of starch or tannins in the leaves. It was noted previously that the addition of superphosphates and potash did not lessen the accumulations of starch and tannins in leaves or increase the yields. This indicates that there is no direct deficiency of these minerals in the soil. It is possible, however, that their absorption is limited by the low level of nitrates in the soils.

In order to investigate this point, the nitrogen, potash, phosphoric acid and lime contents of the leaves giving positive and negative tests for tannins, i.e. from the leaves of plants from the control and from plots manured with sulphate of ammonia were determined. The results are stated in Table III.

TABLE III

Mineral analyses of leaves giving a positive and a negative test for tannins

(Percentage expressed on dry matter)

Treatment	24 September				20 October			
	Nitrogen	Potash	Phosphoric acid	Lime	Nitrogen	Potash	Phosphoric acid	Lime
Control	1·71	4·28	0·421	4·81	1·31	3·16	0·310	4·38
50 lb. N at sowing time	2·85	4·82	0·481	5·32	2·03	4·09	0·354	5·32
50 lb. N at flowering stage	2·63	4·56	0·453	5·51	1·79	3·64	0·328	5·23
50 lb. N + 50 lb. N (at sowing and flowering stages)	2·98	4·58	0·482	5·32	2·38	4·18	0·356	5·26

A study of the results showed that the potash and lime contents of the leaves of plots treated with sulphate of ammonia were higher than those of the leaves of control plots. There was thus an indication that increased absorption of nitrogen was accompanied by an increased absorption of potash and lime. Similar trends were noticeable from an analyses of leaves of plants made in the succeeding cotton seasons. It remains, therefore, unsettled whether deficiency of nitrogen or deficiency of other minerals due to their non-absorption in soils deficient in nitrogen was responsible for the observed accumulation of starch and tannin substances in the leaves. At any rate, the application of potash or phosphoric acid was not found to have any beneficial effect on the crop.

In Table II the yields of plots under different treatments are stated alongside the nitrogen content of the leaves and the tannin tests. It will be seen that the yields of control plots were lower than the yields of plots treated with nitrogen either at sowing time, flowering time or at both stages. Thus the addition of nitrogen had a marked effect on the yields of seed cotton. These results showed that the soil in the area concerned was deficient in nitrogen only, as the addition of other fertilizers in the second experiment had not resulted in increased yields. The detailed results of these field experiments will be discussed elsewhere. The application of nitrogen thus resulted in the non-accumulation of either starch or tannins and in increases in the nitrogen content of the leaves and in the yield of seed cotton.

The weight of seed cotton per boll was also found to increase as a result of the application of ammonium sulphate. The weight of seed cotton per boll in each plot was determined by weighing the seed cotton of bolls of five plants each in two separate units. The weight of seed cotton per boll was higher in plants treated with sulphate of ammonia than in the case of plants in the control plots. There was great improvement in the opening of the bolls as a result of nitrogen applications.

The relationship of tannins and nitrogen deficiency was again confirmed in the cotton season of 1939-40 by analysing the leaves from nitrogen and no-nitrogen plots in a complex field experiment laid out in Square 32C of Lyallpur Agricultural Farm. Tannin tests were made in three replicates of control plots and of plots that had received 50 lb. N as sulphate of ammonia on 14 August 1939. Three sowing dates were included in the experiment, and investigations were undertaken to see the time of appearance of tannins in the

TABLE IV

Accumulation of tannins in leaves of plants from nitrogen and no-nitrogen plots (Three replicates)

Treatments	Dates on which the leaves were tested for tannins (1939)						
	9 Aug.	25 Aug.	8 Sept.	20 Sept.	2 Oct.	14 Oct.	24 Oct.
Control plots—							
Sown on 12 May 1939	+	+	+	+	+	+	+
	+	+	+	+	+	+	+
	+	+	+	+	+	+	+
Sown on 2 June 1939	—	+	+	+	+	+	+
	—	—	+	+	+	+	+
	—	—	+	+	+	+	+
Sown on 22 June 1939	—	—	—	+	+	+	+
	—	—	—	—	+	+	+
	—	—	—	—	+	+	+
Plots treated with sulphate of ammonia on 15-8-39-							
Sown on 12 May 1939	—	—	—	—	—	—	+
	—	—	—	—	—	—	+
	—	—	—	—	—	—	+
Sown on 2 June 1939	—	—	—	—	—	—	+
	—	—	—	—	—	—	+
	—	—	—	—	—	—	+
Sown on 22 June 1939	—	—	—	—	—	—	+
	—	—	—	—	—	—	+
	—	—	—	—	—	—	+

leaves of plants sown at three different dates. The results of the tannin tests made on the fresh samples of leaves during the season are given in Table IV. Accumulation of tannins was first noticed in the control plots sown on 12 May and later in the control plots sown on 2 June and still later in plots sown on 22 June. Thus by delaying sowings the accumulation of tannins was also delayed from 9 September to 2 October, though the flowering phase in the third date of sowing was delayed only by a fortnight as compared with the date of flowering in the first date of sowing.

The leaves of plants in plots treated with sulphate of ammonia under the three sowing dates did not give a positive test for tannins till 24 October when the test is generally given by all cotton plants whether there is a deficiency of nitrogen or not. It must be noted that the nitrogen content of the leaves is as low as 2 per cent at that stage in all cases, except where very high doses of ammonium sulphate have been applied (Table II). In normal soils which are not deficient in nitrogen the nitrogen content of the leaves of 4F Punjab-American cotton was found to be about 2 per cent by the middle of October [Dastur and Ahad, 1941].

The nitrogen content of the leaves of plants in one replicate of the above experiment was determined (Table V). The leaves of five plants in each plot were dried in order to determine total nitrogen, as was done in the previous year. Tannin tests were also made from the same sample.

TABLE V

Total nitrogen and tannin tests of leaves of nitrogen and control plots at different stages

Date	Control plots								Nitrogen plots (50 lb. N on 14-8-39)							
	21 Aug. 1939		10 Sept. 1939		30 Sept. 1939		20 Oct. 1939		21 Aug. 1939		10 Sept. 1939		30 Sept. 1939		20 Oct. 1939	
(1939)	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin	Percentage of N	Tannin
12 May . .	2·14	+	1·63	+	1·50	+	1·31	+	2·47	—	2·84	—	2·12	+	1·76	+
2 June . .	2·20	+	1·73	+	1·60	+	1·32	+	2·67	—	3·04	—	2·52	—	2·11	+
22 June . .	2·98	—	2·39	+	1·97	+	1·81	+	3·53	—	3·33	—	3·32	—	2·70	—

The results showed that the nitrogen content of the leaves in the control plots was at a lower level than that of the leaves in the plots treated with sulphate of ammonia. The relationship between tannin and nitrogen deficiency in leaves was again established. In the plot sown on 22 June the nitrogen content of the leaves was at a higher level than that of the leaves in the early-sown plots.

Similar results showing the relationship of tannins and nitrogen content were obtained in other experiments, but, as there was no other special feature in those results, they have not been added here.

The yield of seed cotton from each plot and the weight of seed cotton per boll are given in Table VI.

TABLE VI

Yield of seed cotton per plot in lb. and weight of seed cotton in gm. per boll in nitrogen and no-nitrogen plots (1939-40)

Control				50 lb. N at flowering			
Plot No.	Date of sowing (1939)	Wt of seed cotton per boll in gm.	Yield per plot in lb.	Plot No.	Date of sowing (1939)	Wt of seed cotton per boll in gm.	Yield per plot in lb.
8	12 May .	0·91	6·25	3	12 May .	1·48	17·2
42	12 May .	1·11	8·75	13	12 May .	1·49	18·5
38	12 May .	0·98	7·50	45	12 May .	1·77	18·0
	Mean .	1·00	7·50		Mean .	1·58	17·9
57	2 June .	1·36	9·10	16	2 June .	1·39	17·7
62	2 June .	1·14	8·90	29	2 June .	1·72	22·1
15	2 June .	1·16	8·50	50	2 June .	1·90	21·1
	Mean .	1·23	8·80		Mean .	1·67	20·3
10	22 June .	1·23	7·25	7	22 June .	1·55	12·3
49	22 June .	1·52	12·50	23	22 June .	1·15	11·8
71	22 June .	1·48	11·25	39	22 June .	1·75	16·9
	Mean .	1·41	10·30		Mean .	1·48	13·6

In the control plots the yield and weight of seed cotton per boll improved as the sowings were delayed. The tannin tests also indicated that the deficiency of nitrogen arose later in the plots sown late. This was further supported by the results of nitrogen content given in Table V.

The yields from plots treated with sulphate of ammonia were higher than those from control plot sown on the same date, while the weight of seed cotton per boll was higher than that from the corresponding control plots only in the first two dates of sowing. The plots sown on 22 June 1939 responded to a smaller extent to the application of sulphate of ammonia than in the other two cases. This was due to lack of vegetative growth, because of which the plants did not suffer from nitrogen deficiency as much as the plants sown earlier. Hence the last-sown plots had not profitted by the application of sulphate of ammonia to the same extent as the early-sown plots.

A detailed study of the above relationship between the accumulation of tannins, nitrogen content of the leaves and the yield, plot by plot, in the first field experiment of 1938-39 revealed that applications of sulphate of ammonia had not resulted in as high an increase in yield in some plots as in others though the tannin test was negative in September and the nitrogen content was higher in these plots than in the control plot. The results of such plots are given in Table VII.

TABLE VII

Yields and nitrogen contents of plots which have saline sub-soil

Plot No.	Treatment	Tannin test on 22 Sept. 1939	Percentage of nitrogen on 20 Oct. 1939	Weight of seed cotton per boll	Yields in lb. per plot
1	Control	+	1·46	1·54	15·8
4	Control	+	1·62	1·26	13·1
2	50 lb. N at sowing . . .	—	2·78	1·50	20·5
7	50 lb. N at sowing . . .	—	2·53	1·23	13·7
3	50 lb. N at flowering . .	—	2·65	1·74	23·5
54	50 lb. N at flowering . .	—	2·08	1·50	19·5
6	50 lb. N at each stage . .	—	3·12	1·50	21·5
15	50 lb. N at each stage . .	—	2·77	2·04	25·7

As the results show, there was not as great a response to nitrogen as in the results given previously. There was no increase in the weight of seed cotton per boll as compared with the control as a result of nitrogen application. A comparison of the results given in Tables II and IV with those in Table VII will show these differences.

Similar results were obtained in the plots of the second field experiment of 1938-39 when there was a smaller response in yield to nitrogenous fertilizers and there was no increase in weight of seed cotton per boll in the manured plots.

The physical and chemical analyses of the soils in these plots and of the soils of the fields of the second field experiment referred to above were made foot by foot down to a depth of 6 ft. It was found that the subsoil in all these cases either contained sodium clay or very high concentrations of free sodium salts at varying depths. These soil investigations and their effects on the growth and yield of the cotton plant will be described in another contribution on the subject. The application of nitrogenous fertilizers when such soil conditions exist do not greatly improve the yields or the opening of the bolls, on account of other disturbances produced in the plant metabolism, though the deficiency of nitrogen does exist there along with saline subsoil.

CONCLUSIONS

The accumulation of tannins in leaves, as the results show, is found to occur when the nitrogen content falls below a certain level. If tannins are found in the leaves at the flowering stage of the plant, i.e. from the third week of August to the middle of September, it may be regarded as a biochemical index of nitrogen deficiency in the plant, as the nitrogen content of the leaves during that stage is found to fall to the level of 2·5 per cent or less. The cotton plant absorbs nitrogen and other minerals in maximum amounts during the flowering phase, as shown in a previous contribution [Dastur and Ahad, 1941]. This relationship between low nitrogen content of the leaves and the accumulation of tannins can be of practical value. If sulphate of ammonia is applied to a cotton crop when its leaves give a positive test for tannin at the flowering stage, the yield will greatly increase and the opening of the bolls will be greatly improved, except where the subsoil is saline. If nitrogen deficiency does not occur in the plants growing on saline subsoils, a positive tannin reaction will not be given. The difficulty arises only when both conditions occur together. In such a case a test for tannin will be positive, but the application of sulphate of ammonia may not result in as high an increase in yield as in the case when salinity does not exist.

The presence of salinity in the subsoil can be detected by the external appearance of the plants, as in such cases the plants are either stunted in growth or, if they are well grown, the leaves in August-September, about a week after irrigation, show drooping from which they do not recover. The leaves of plants growing on sandy and saline soils curl upwards, forming discs, and become bronze coloured in September. If a positive reaction for tannin is given by plants in such fields, sulphate of ammonia may not be applied. The desirability of modifying this test in such a manner that salinity in the subsoil can be detected apart from a deficiency of nitrogen in the soil is being examined.

Attempts were, therefore, made to put to a practical test the relationship between nitrogen deficiency and accumulation of tannin in leaves in the cotton season of 1939-40. The tests for tannins were carried out in fields of Lyallpur Agricultural Farm and in fields of zemindars. The test was made in duplicate samples of five plants each in the third and fourth weeks of August. Forty-five fields were tested and whenever a positive test for tannins was given, sulphate of ammonia was applied to those fields at the rate of 2 mds. per acre before the next irrigation. Some portions of each field were retained unmanured so as to serve as control. Whenever it was possible to do so, adequate replicates were provided, otherwise only two replicates could be kept. It is not possible to divide a standing crop into a large number of plots on account of various difficulties, such as the irregular stand of the crop, the shape and size of the field, difficulties of making strong bunds between plots and the situation of water channels which are important for irrigating the control and treated plots separately so that the water from the treated plots does not pass into the control plots.

Sulphate of ammonia was also added at the same rate in some fields where a negative test for tannin was given, for the sake of further confirmation of the above relationship. It is interesting to see the increase in yield when the tannin test was negative.

At one centre sulphate of ammonia was added as late as 6 October. As already stated, all crops generally give a positive test in October and therefore it was a normal feature of leaves at that stage. It was, therefore, necessary to study the effect on yield of additions of sulphate of ammonia at the rate of 1½ mds per acre as late as October. Four replicates were provided.

The mean yields of control and treated plots, the cost of the fertilizer (at pre-war rates) and the net profits after deducting the cost of fertilizer are given in Table VIII where a positive test was given and in Table IX where a negative test was given. The yields were recorded by the respective zemindars and were sent to the author, except in the case of the observations at Lyallpur Agricultural Farm.

TABLE VIII

Response to application of sulphate of ammonia to cotton crop, when a positive tannin test was given, at the flowering stage

Place	Square number	Variety	Mean yield per acre in mds		Cost of $(NH_4)_2SO_4$ per acre		Net profit* per acre	
			Control	Treated	Rs.	A.	Rs.	A.
Lyallpur . .	Sq. 32C, Fds 1-4 . . .	4F** .	7·27	13·21	15	0	44	6
,, . . .	,, Fds 5-6 .	4F ** .	5·50	9·8	7	8	27	8
,, . . .	,, ,, . .	*Desi* ** .	9·6	14·3	7	8	34	10
Okara . . .	Chak 5A, Sq. 4 . . .	*Desi* .	14·3	17·2	10	0	16	1
,, . . .	,, Sq. 5 . . .	American .	4·7	8·8	10	0	31	0
,, . . .	,, Sq. 5 . . .	,, .	6·3	8·3	10	0	10	0
,, . . .	Chak 8, Sq. 16 . . .	289F/K25 .	7·2	10·8	10	0	26	0
,, . . .	,, Sq. 21 . . .	289F/K25	9·0	11·5	10	0	15	0
,, . . .	Chak 10, Sq. 38K . .	289F/K25	6·8	7·4	10	0	—4	0
,, . . .	,, Sq. 35 . .	*Desi* .	15·2	20·7	10	0	45	0
,, . . .	,, Sq. 56 . . .	43F .	14·5	17·2	10	0	17	0
Average for Okara .			9·8	12·7	...		19	0
Khanewal B. C. G. A.	Chak 83, Sq. 45 . . .	289F/K25	2·55	4·65	10	0	11	0
,, .	,, Sq. 35 . . .	*Desi* .	3·63	5·54	10	0	7	3
Abdul Hakim . .	8R/1R , Sq. 9 . . .	4F** .	9·42	16·13	10	0	57	1
	Sq. 9 . . .	*Desi* ** .	9·93	13·34	10	0	20	11
Average of all experiments	......	...	7·21	11·21	10	0	27	11
Risalewala Seed Farm	Sq. . . . . Fertilizer applied on 6 October	L S 8 .	3·36	3·86	7	8	—2	8

*For calculating net profit, the price for Americans is taken as Rs. 10 per md. and for *desi* as Rs. 9 per md. in 1939.

** = Replicated six times or more.

It is clear from the results that the application of sulphate of ammonia, when the positive test for tannin was given by a crop at the flowering stage, gave profitable returns, the actual gain depending on the price of the fertilizer, the market price of *kapas* and the stand of cotton. The seasonal conditions in October and a part of November were unfavourable during the season of 1939-40, otherwise it was expected that the increases in yields would have been higher than they were.

TABLE IX

Response to applications of sulphate of ammonia and other manures to cotton crops when negative tannin tests were given by the leaves at the flowering stage

(Replicated seven times or more)

Place	Square No.	Variety	Mean yield per acre (mds)			Net profit
			Control	Treated	Cost of fertilizer*	
					Rs. A.	Rs. A.
Lyallpur . .	$27D_2$	4F	3·4	4·0	15 0 (NP)	—9 0
,, . . .	,, ...	,,	3·4	4·1	61 14 (G.M.+NP)	—54 14
,, . . .	,, ...	,,	3·4	2·3	46 14 (G.M.)	—46 14
,, . . .	$27D_1$	,,	13·44	13·05	15 0 (N)	—15 14
Khanewal B. C. G. A.	Chak 83, Sq. 32 . .	289F/K25	1·51	1·71	10 0 (N)	—8 0
Montgomery . .	Farm	4F	1·02	1·13	15 0 (N)	—3 3

* G. M. = Green manuring, N = Sulphate of ammonia, P = Superphosphate

The results also showed that no benefit was derived from the application of sulphate of ammonia to fields where the leaves of the crop did not give a positive test for tannin. In some cases there was no increase in yield at all.

It was also of no benefit to apply sulphate of ammonia as late as October to crops even though a positive test was given.

These results are in conformity with the experience of the Department of Agriculture and other zemindars in their manurial experiments. The response to sulphate of ammonia varied in their experiments from year to year and field to field. At some places the use of sulphate of ammonia was found to be economical, whilst a contrary result was obtained at other places. Various large-scale zemindars in the Punjab have given up the use of sulphate of ammonia as they did not find it on the whole beneficial. The causes of the varying responses can now be traced to the soil conditions that are very variable in the Punjab. The presence of sodium salts in the soil and the application of sulphate of ammonia to fields in which it was not needed by the crop are the two chief factors that have made the use of sulphate of ammonia unprofitable. Crowther [1939] deplores the fact that cultivators in the Punjab do not use sulphate of ammonia for manuring their cottons, but they have reasons for not doing so as the present investigation has shown.

There are great practical possibilities in the relationship that has been established between nitrogen content of the leaves and the accumulation of tannins. It is not possible to ascertain by making chemical analysis of soils for available nitrogen whether a crop suffers from nitrogen deficiency or not. Even though the nitrate nitrogen in the soil is found to be nil in August or September by the phenoldisulphonic method, the yield may be normal. Again the crop yields were rather low or normal even though the nitrate nitrogen varied in both cases from four to six parts per million at the flowering stage. These statements can be supported by data to be published later in another contribution, but the results given in Table IX also support them as the addition of extra nitrogen at the flowering stage of the plant did not result in increased yields. A plant is the best indicator of its wants which cannot be always determined by soil analysis alone. The tannin test described above makes the detection of nitrogen deficiency possible at an earlier stage, i.e. before the leaves externally show the symptoms of nitrogen starvation, such as yellowing and shedding. It also enables the cultivator to remedy the deficiency before it is too late.

It is possible that deficiency of nitrogen generally occurs in those fields where tannin tests are positive each year that the cotton crop is grown in them. The question whether it is possible by means of this test to label a field once for all time as one that will suffer from nitrogen deficiency whenever cotton is grown in it and will give an economic response to the application of a nitrogenous fertilizer is under investigation at present. So far the total nitrogen of the leaves of 4F Punjab-American cotton plants only has been determined. It is, therefore, not possible to say at this stage the level of total nitrogen in the leaves of other varieties and strains of cotton when tannins would appear in them, though some of those varieties and strains did give positive tannin tests, as can be seen from Table VIII, and responded to applications of sulphate of ammonia.

SUMMARY

Formation of tannin deposits in the mesophyll cells of the leaves of the 4F Punjab-American cotton plants which later developed premature yellowing and shedding of leaves and bad opening of the bolls was described in a previous contribution by the author [Dastur, 1939].

In the cotton season of 1937-38, whilst making periodic examination of the leaves, it was noticed that these deposits were absent in plants from plots treated with ammonium sulphate, while they were present in the leaves of plants from the control plots and from plots manured with potash or superphosphate. It was, therefore, undertaken to investigate the possible relationship between the formation of tannins in leaves and their total nitrogen content in the season of 1938-39.

Microscopic method for testing the presence of tannins in leaves was replaced by a chemical method.

Leaves of plants from two field experiments, in which nitrogenous fertilizers were among the treatments, were tested periodically for tannins and it was found that a test for tannins was given by the leaves of plants from the control plots by the beginning of September, while the test was negative in leaves of plants from plots manured with nitrogenous fertilizers.

Analysis of the leaves for total nitrogen showed that the nitrogen content of the leaves giving a negative test was significantly higher than the nitrogen content of the leaves giving a positive test. Similarly the yield and the opening of the bolls, i.e. weights of seed cotton per boll were higher of the manured plots than of the control plots.

The above relationship between tannins and nitrogen deficiency was again confirmed in the cotton season of 1939-40,

A positive tannin test was generally given by leaves, whose nitrogen content was in the neighbourhood of 2·5 per cent of the dry matter. By sowing the cotton crop later than the normal practice tannins developed later in the leaves than in the leaves of early-sown plants. The analysis of the leaves under different sowing dates again confirmed the same relationship between the nitrogen content of the leaves and tannins.

A positive test for tannins in leaves of the cotton plant in the Punjab at its flowering phase (August-September) is thus an index of nitrogen deficiency at that stage. This fact was made use of in detecting and remedying the nitrogen deficiency in cotton crops during 1939-40 season. The test for tannins was made in 45 fields located in different districts in the third and fourth weeks of August. Whenever a positive test was recorded, sulphate of ammonia at the rate of 2 mds per acre was applied. Controls were also included. The fertilizer was also applied in some fields where negative test was given. In the former case the response to the fertilizer was high and profitable, while in the latter case the response was either nil or low and was uneconomic.

Practical possibilities of this test are discussed.

ACKNOWLEDGEMENTS

The author's thanks are due to Mr H. R. Stewart, C.I.E., I.A.S., Director of Agriculture, Punjab, for correcting the manuscript and for providing all facilities for work reported in this paper.

REFERENCES

Crowther, F. (1939). *Agric. & Livestock in Ind.* **9**, 401

Dastur, R. H. (1939). *Ind. J. Agric. Sci.* **9**, 291-303

Dastur, R. H. and Ahad, A. (1941). *Ind. J. Agric. Sci.* **11**, 279

FOOT-ROT OF GRAM (*CICER ARIETINUM* L.) CAUSED BY *OPERCULELLA PADWICKII* NOV. GEN., NOV. SPEC.

BY

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(Received for publication on 3 October 1940)

(With Plate XIV)

It has recently been proved by Prasad and Padwick [1939] that a wilt disease of gram (*Cicer arietinum* L.) is caused by a species of *Fusarium*. During the season 1938-39 a considerable number of wilted plants collected by Mr K. M. Dutt from Karnal (Punjab) yielded on isolation a quite different fungus which in culture produced pycnidia with spores of a very curious form. In the season 1939-40 this same pycnidial fungus was isolated from many diseased plants at the Imperial Agricultural Research Institute, Delhi. Taking the results of isolations at Karnal and Delhi together, the pycnidial fungus was obtained from eight out of nine varieties of gram, and 85 isolates of it were obtained as compared with 111 isolates of *Fusarium*.

INOCULATION EXPERIMENTS

Inoculation experiments were made by three different methods :—

(1) By immersion of seeds in a suspension of spores made from a culture of the fungus.

(2) By sowing the seeds in sterilized soil infested with cultures of the fungus grown on a sterilized mixture of soil and corn-meal.

(3) By spraying the foliage with a spore suspension.

From repeated experiments made so far it has been possible to obtain heavy infection regularly only by method 2 (soil infestation). With 25 different varieties, death of seedlings varying from 14 to 81 per cent was obtained, while the control plants remained healthy. Re-isolations of the same fungus were made from the infected plants. By method 1 (immersion of seeds in a spore suspension) only a small number of plants took infection, while method 3 (spraying the foliage with a spore suspension) was unsuccessful.

SYMPTOMS OF THE DISEASE

The affected plants begin to dry from the tip downwards. The leaves assume a pale green colour, and later become yellowish and finally drop off. The collar of the plant becomes dark brown in colour and in some cases the roots and rootlets are also attacked. Microscopic examination of stem and root tissue reveals broad granular inter and intra-cellular septate mycelium within the tissues of the host. The fungus does not directly attack the foliage as in the case of blight (*Mycosphærella rabiei* Kovachevsky). No fruiting bodies have been found on the host either in nature or in artificial inoculation experiments. Various attempts were made to induce the causal organism to produce its fruiting bodies on its host. The pieces of infected material

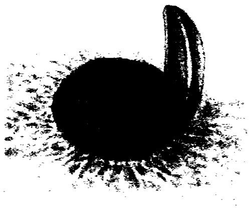

Fig. 1
Pycnidium with open lid (×24)

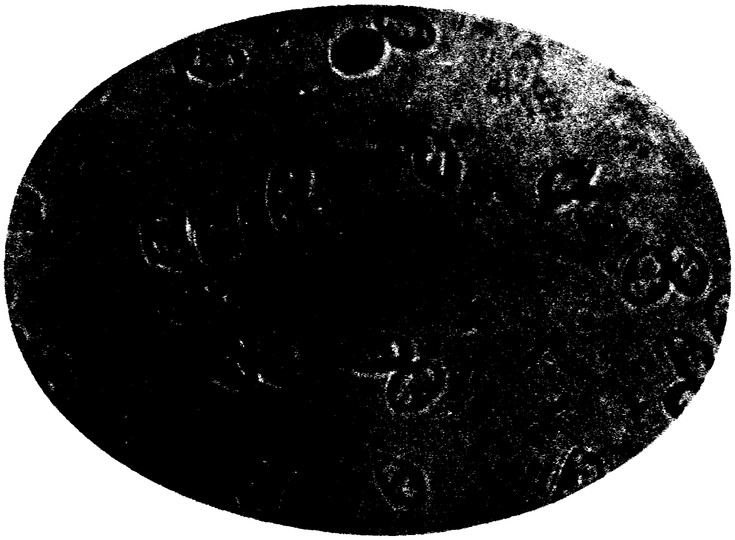

Fig. 2. Pycnidiospores (×750)

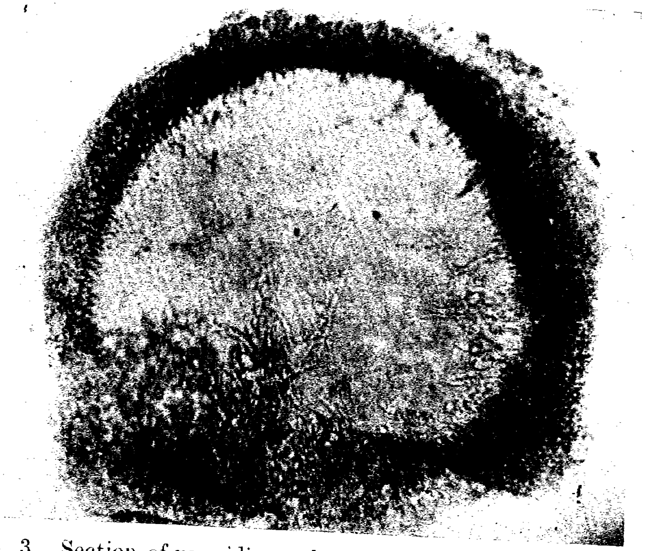

Fig. 3. Section of pycnidium, showing branched conidiophores with a lateral conidium still attached (×205)

were held at different temperatures ranging from 10 to 30°C. for a period of eight months and were examined periodically, but the attempt was unsuccessful. Some of the infected material was buried in pots which were watered once a week to keep the soil wet and examined every fortnight. After about three months, pycnidia of the fungus developed on some of the infected pieces.

THE FUNGUS

On oat-meal agar or potato dextrose agar the fungus produces a white felt of mycelium on the substratum, and at the end of a week yellowish, immature pycnidia develop, at first immersed and later erumpent. The pycnidia are not produced in a stroma. At first they are yellow, but at maturity they become carbonaceous, and a yellowish-white spore mass oozes out from the ostiole, or alternatively the upper portion of the pycnidium is forced off as a lid remaining attached at one side so that the structure appears as a hinged shield (Plate XIV, fig. 1). They may measure up to 800µ in diameter. The spores (Plate XIV, fig. 2), which are produced in great abundance, are quite irregular in shape, hyaline, and borne on two kinds of conidiophores, the shorter being unbranched and of average length 83µ, forming a compact layer on the entire inner surface of the pycnidium, the longer ones being sparsely branched and sometimes septate and producing the spores laterally on minute sterigmata (Plate XIV, fig. 3).

The fungus, belonging to the Sphæropsidaceæ, has certain peculiarities which make it difficult to place it in any known genus.

Three fungi have been described which have irregularly shaped pycnidiospores. Tassi [1900] described a new genus *Trigonosporium* with a single species (*T. australiense*). The pycnidia are sub-globose, sub-cutaneous erumpent, perforated with an apical pore, and 200-250µ in diameter. The spores are distinctly triangular when viewed from above, ellipsoid to cylindrical when seen laterally, and measure 4-5µ in diameter. The genus *Vanderystiella*, described by Hennings [1908] is represented by a single species *V. leopoldvilliana*. It has round to disc-shaped, angular, dark acervuli, 60-130µ in diameter; short hyaline conidiophores; and fusoid to quadrangular, pointed, hyaline to dark conidia, 10-14 × 5-7µ in size. A species of *Phomopsis*, namely *P. Boycei*, described by Hahn [1930] also has irregularly fusoid spores with salient angles, so that they become three or four sided. They are borne in ecto-stromatic, simple or compound imbedded pycnidia, the longer ones being 'plurilocular, the chambers fusing irregularly and tending to form a unilocular cavity lined with a convoluted hymenium.'

Although all these fungi possess one or more characteristics which are reminiscent of the gram wilt fungus, none has a non-stromatic pycnidium with a circumscissile lid and containing irregular hyaline spores, and there seems to be no genus so far described in which such a fungus can be included. It is proposed to erect a new monotypic genus to encompass the characteristics of this fungus, and to call it *Operculella* on account of its peculiar method of liberating spores.

OPERCULELLA GEN. NOV.

Pycnidia unilocular, discoid to sub-globose, immersed at first, later erumpent, opening with an apical pore or by means of a hinged lid. Conidiophores of two kinds; the shorter ones simple, lining the walls of the pycnidium

and bearing spores terminally; the longer ones branched and sometimes septate and bearing spores laterally as well as terminally. Spores irregular in shape, continuous, hyaline.

Latin diagnosis

Pycnidia unilocularia, discoidea vel sub-globosa, primo immersa, dein erumpentia, poro apicali vel saepe operculo dehiscentia. Sporophora diversa; alia brevia, simplicia, marginem, loculi vestientia, sporulasque terminales gerentia; alia longioria, interdum septata, sporulas laterales etiam gerentia. Sporulae irregulares uniloculares hyalinæ.

OPERCULELLA PADWICKII SPEC. NOV.

Pycnidia as in the genus, finally carbonaceous, 270-810μ diameter. Shorter sporophores averaging 83μ in length; longer sporophores bearing spores laterally on minute sterigmata and terminally. Spores hyaline, yellowish-white in mass, 7·4-16·6 × 5·5-11·1μ.

Habitat.—In dead stems of *Cicer arietinum* L., Karnal, Punjab (December, 1938); Delhi; Gurdaspur, Punjab. Type in Herb. Crypt. Ind. Orient., I. A. R. I., New Delhi.

Latin diagnosis

Pycnidiis ut in genere, postremo carbonaceis, 270-810μ diameter. Sporophoris brevioribus, in medio 83μ longis; sporophoris longioribus sporulas laterales ex sterigmatibus minutis gerentibus. Sporulis hyalinis, in cumulo ochroleucis, 7·4-16·6 × 5·5-11·1μ.

Hab.—In caulibus emortuis *Ciceri arietini* L., Karnal, Punjab (December, 1938); Delhi; Gurdaspur, Punjab. Typus in Herb. Crypt. Ind. Orient., I. A. R. I., New Delhi.

SUMMARY

A pycnidial fungus which causes foot-rot of gram (*Cicer arietinum* L.) at Karnal (Punjab) and Delhi is described. The fungus belongs to the Sphæropsidaceæ. It produces irregularly shaped, hyaline spores which emerge through a minute apical pore or force open the top of the spherical or discoid pycnidium. The fungus is considered to belong to a new genus for which the name *Operculella* is proposed. The gram foot-rot fungus is named *O. Padwickii*.

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Grateful acknowledgements are due to Dr G. Watts Padwick, Imperial Mycologist, for the constant interest he took in the diagnosis of this fungus and for going through the manuscript, and to Dr B. B. Mundker for making some useful suggestions.

The author wishes to express his gratitude to Mr E. W. Mason, of the Imperial Mycological Institute, for confirming his opinion with regard to the placing of the species in a new genus and for kindly providing the Latin diagnoses.

REFERENCES

Hahn, G. G. (1930). *Trans. Brit. Mycol. Soc.* **15**, 32-93

Hennings, P. (1908). *Ann. Mus. Congo II, fasc III*, 229 (In Sacc. *Syll. fung.* **22**, 1193: 1913)

Prasad, N. and Padwick, G. W. (1939). *Ind. J. Agric. Sci.* **9**, 371-80

Tassi, F. (1900). *Bull. Lab. Ort. Bot. Siena* **90** (In Sacc. *Syll. fung.* **16**, 892 : 1902)

REVIEWS

The principles of fumigation of insect pests in stored produce (H. M. Stationery Office: Pp. 28, 1940; Price 6*d.*)

EVERY year insects damage or destroy millions of pounds worth of stored produce, mainly foodstuffs. The ravages of these destructive pests can be prevented to a great extent simply by keeping the warehouses clean. But if the produce or the warehouse is badly infested, it may become necessary to adopt other methods, such as fumigation, to rid them of infestation. Fumigation is a job which must be carried out by experts. The Department of Scientific and Industrial Research has just issued a pamphlet describing the scientific principles underlying the successful fumigation of insect pests that infest stored produce. This pamphlet is intended to help the expert to apply the results of the most recent findings of science in this important and practical field.

After discussing the varying nature of fumigants and describing suitable apparatus for vapourizing these where necessary, graphs are given to show how stirring the air aids the effective distribution of the fumigant.

Penetration of the gas into the goods depends on how the produce is stacked, while the nature of the building affects the amount of fumigant which will ‘ cling ’ or leak away. Suggestions are made for the most effective use of the fumigant, and for ventilation of the building afterwards. Finally the pamphlet deals with the means for observing the effectiveness of the fumigation in killing the insects in all parts of the building.

Insect pests of Burma. By C. C. Ghosh, B.A., F.R.E.S. (Published by Superintendent, Government Printing and Stationery, Burma, 1940: Pp. 216; Price Rs. 7-8)

MR Ghosh deserves congratulations on his book *Insect pests of Burma*, which is a very timely publication, considering that there is at present little available information on the Burman insect pests. In this publication an attempt has been made to acquaint general readers with the elementary facts about insect life and with the common insect pests which have been observed to occur in Burma. Simple methods, wherever possible, have been suggested for action against the pests. Technical descriptions have been reduced to the minimum and the publication appears to be meant primarily for general readers. The book is divided into two parts. Part I deals with general facts about insect life, classification, and the prevention and control of damage by insects, both chemical and biological. Part II deals with the general pests and the pests of the different agricultural crops. In addition, Part II gives useful information on the pests of garden plants, plantation crops, fruit trees and the pests in houses and stores. The get-up of the book is excellent and the illustrations are profuse and very well produced. The book is a valuable addition to the literature on tropical insect pests. (S. C. R.)

PLANT QUARANTINE NOTIFICATIONS

INDIA

Notification No. F.- 50-13 (20) 39-A, dated November 20, 1940

IN exercise of the powers conferred by sections 4A and 4D of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make, with effect from the 1st February 1941, the following rules for regulating the transport from the Punjab, the North-West Frontier Province and British Baluchistan to any other Province in British India of certain articles which are likely to carry the destructive insect known as San José Scale (*Aspidiotus perniciosus*) and thereby cause infection to crops, namely :—

1. In these rules, ' infected Province ' means the Punjab, the North-West Frontier Province or British Baluchistan.

2. The articles to which these rules apply are :—

(*a*) the following plants, namely, *akik*, alder, almond, apple, apricot, beech, bhang, birch, crab apple, celtis, cherry, chestnut, currant, elm, eucalyptus, grape vine, green-gage, hawthorn, lilac, mountain ash, mulberry, oak, peach, pear, persimmon, poplar, plum, quince, raspberry, rose, strawberry, walnut and willow ;

(*b*) the following plant materials, namely buds, cuttings, scions, grafts, bulbs, leaves, seedlings, tubers and rhizomes, of the plants specified in clause (*a*); and

(*c*) any articles used in packing or wrapping up any of the plants and plant materials mentioned in clauses (*a*) and (*b*).

Note.—These rules do not apply to the fruits of the plants mentioned in clause (*a*).

3. No article to which these rules apply shall be transported from an infected Province to any other Province in British India—

(*a*) by means of letter or sample post or by air,

(*b*) by road except by such routes as may be specified by the Government of the other Province, or

(*c*) by railway or inland steam vessel unless the consignment is accompanied by a certificate in the form set forth in the Schedule annexed to these rules and signed by the authority specified therein.

Schedule

This is to certify that the living plants/plant materials included in the consignment of which particulars are given below were thoroughly examined on .... (*date*) by .... (*name and designation of official*)........................a duly authorized official of the............................. (*name of Department*).......... and that the consignment including the packing covered by this certificate has been adequately treated and fumigated with hydrocyanic acid gas immediately $\frac{\text{Prior}}{\text{Subsequent}}$ to inspection and made free from living San José Scale.

Date of examination and fumigation ....
Particulars of consignment ....
No. and description of packages ....
Distinguishing marks ....
Description of living plants or plant materials ....
Exported by ....
Name and address of the consignee ....

Signature of certifying authority*. ....

Designation ....

**Note*.—The above certificate should be signed—

(*a*) in the Punjab, by the Entomologist, Punjab Agricultural College, Lyallpur, or such other officer as may be authorized by the Director of Agriculture, Punjab in this behalf,

(*b*) in the North-West Frontier Province, by the Agricultural Officer of that Province, or such other officer as may be authorized by the Provincial Government in this behalf, and

(*c*) in British Baluchistan, by the Agricultural Officer, Baluchistan, or such other officer as may be authorized by the Chief Commissioner in this behalf.

Notification No. F. 50-13 (21) 39-A., dated November 20, 1940

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make, with effect from the 1st February 1941, the following rules for the purpose of regulating the import into British India of certain articles which are likely to carry the destructive insect known as San José Scale (*Aspidiotus perniciosus*) and thereby cause infection to crops, namely :—

1. In these rules, ' infected area ' means the States of Jammu and Kashmir, Chamba, Mandi, Suket, Balsan, Jubbal, Koti, Kumarsain, Madhan, Baghat and Bashahr and the hill tracts of Patiala State comprising the following Parganas, namely :—

Ajmergarh, Baghet, Bagi, Bagri Kalan, Bagri Khurd, Bharoli Kalan, Bharoli Khurd, Chail, Haripur, Jhabrot, Kaimli, Kaljun, Kootan Awal, Keotan Doyam, Khushala, Nali Dharti, Pashgaun and Shatrol.

2. The articles to which these rules apply are :—

(*a*) the following plants, namely *akik*, alder, almond, apple, apricot, beech, bhang, birch, crab-apple, celtis, cherry, chestnut, currant, elm, eucalyptus, grape vine, green-gage, hawthorn, lilac, mountain ash, mulberry, oak, peach, pear, persimmon, poplar, plum, quince, raspberry, rose, strawberry, walnut and willow ;

(*b*) the following plant materials, namely buds, cuttings, scions, grafts, bulbs, leaves, seedlings, tubers, and rhizomes, of the plants specified in clause (*a*) ; and

(*c*) any article used in packing or wrapping up any of the plants and plant materials mentioned in clauses (*a*) and (*b*).

NOTE.—These rules do not apply to the fruits of the plants mentioned in clause (*a*) ;

3. No article to which these rules apply shall be imported from an infected area into British India—

(*a*) by railway or inland steam vessel unless the consignment is accompanied by a certificate in the form set forth in the Schedule annexed to these rules and signed by the authority specified therein, or

(*b*) by land except by the following roads :—

(*i*) Srinagar-Kohala-Murree road ;
(*ii*) Srinagar-Gari Habibullah-Abbottabad-Haripur-Hassanabdal road ;
(*iii*) Srinagar-Jammu-Sialkot road ;
(*iv*) Dalhousie-Pathankot road ;
(*v*) Oot-Kulu road ;
(*vi*) Mandi-Baijnath-Palampur road ;
(*vii*) Bilaspur-Rupar road ;
(*viii*) Fagu-Simla road ;
(*ix*) Theog-Simla road ;
(*x*) Koti-Simla road ;
(*xi*) Kotgarh-Simla road ;
(*xii*) Simla-Kalka-Ambala road.

Schedule

This is to certify that the living plants/plant materials included in the consignment of which particulars are given below were thoroughly examined on .... (*date*) by .... (*name and designation of official*).................... a duly authorized official of the .... (*name of Department*)............

and that the consignment including the packing covered by this certificate has been adequately treated and fumigated with hydrocyanic acid gas immediately $\frac{\text{Prior}}{\text{Subsequent}}$ to inspection and made free from living San José Scale.

Date of examination and fumigation..
Particulars of consignment ....
Number and description of packages ....
Distinguishing marks ....
Description of living plants or plant materials ....
Exported by ....
Name and address of the consignee ....
Signature of certifying authority* ....
Designation ....

*NOTE.—The above certificate should be signed—

(a) in Kashmir, by the Director of Agriculture, Kashmir, or such other officer or officers as may be authorized by the Kashmir Durbar in this behalf.

(b) in other States mentioned in rule 1 by such officers as may be authorized by the Durbars concerned.

Notification No. F. 30-7 (34)/37-A., dated December 12, 1940

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

In the First Schedule annexed to the said notification, in columns 2 and 3—

(1) the entry relating to ' Dutch Indies ' shall be omitted, and

(2) after the entry relating to ' Mozambique ', the following entry shall be inserted, namely :—

Netherlands Indies . . The Department of Economic Affairs

Notification No. F. 193/40 A., dated February 3, 1941

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make the following Order for the purpose of prohibiting, regulating and restricting the import of live insects into British India :—

1. In this Order ' insect ' means a living insect, and includes eggs of an insect.
2. No insect shall be imported into British India unless it is accompanied by—
   (a) a special permit authorizing such importation issued by the Central Government or by an Officer authorized by the Central Government in this behalf; and
   (b) a certificate of freedom from disease granted by an Entomologist of the Government of the country of origin.
3. The provisions of paragraph 2 of this Order shall not apply to—
   (a) bees and silkworms ;
   (b) parasites and destroyers of injurious insects or other pests intended for the control of such insects or pests, when imported by the authorities of the Institutions named below :—

The Imperial Agricultural Research Institute, New Delhi
The Imperial Veterinary Research Institute, Mukteswar
The Forst Research Institute and College, Dehra Dun
The Public Health Commissioner with the Government of India
The Indian Research Fund Association
The Departments of Agriculture, Madras, Bombay, Bengal, United Provinces, Punjab, Bihar, Central Provinces and Berar, Assam, North-West Frontier Province, Sind, Orissa and Mysore.

UNITED STATES OF AMERICA

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

LIST OF UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE, SERVICES AND REGULATORY ANNOUNCEMENTS

1. *Quarantine and other official announcements* :—Japanese Beetle Quarantine—modifications
2. *Service and Regulatory Announcements*.—January to March 1940

GIPD—3 S—448 IC of AR—10-5.41—800.

ORIGINAL ARTICLES

ECONOMICS OF MANURING

BY

P. V. SUKHATME, PH.D., D.SC. (LOND.)

Statistician, Imperial Council of Agricultural Research, New Delhi

(Received for publication on 3 March 1941)

(With four text-figures)

AN all-important question regarding manuring is, ' Does it pay ? ' This means, of course, ' Does the money value of the additional crop obtained exceed the price paid for the manure applied ? ' A subsidiary but also important question is, 'At what point in the price paid for the manure applied does it cease to pay ? ' Owing to the high prices of artificial manures during war time the economics of manuring has received a good deal of attention in a few places in India, but as Burns [1940] has recently pointed out, ' a great deal remains to be done in getting the economics of manuring down to a precision that can be expressed in a table or graph '.

The word ' precision ' in the above quotation is exceedingly important. The fact that the value of the extra crop raised as a result of manuring is more than the price of the manure applied, including the incidental charges of application, cannot by itself, without consideration of the experimental errors to which the excess (or profit) is subject, establish the generalization that it pays to manure. The appropriate factor to consider would appear to be the index of probability that a profit as large as or larger than the one observed in the experiment conducted would occur in future. Only when this probability is found to be sufficiently large should we be justified in pronouncing a verdict that it would pay to manure a crop.

In a note published in *Current Science*, the author [Sukhatme, 1941] has briefly outlined the approach to the study of manurial trials from the economic aspect explained above. The main object of this paper is to present the test of significance for profit in its application to some actual data. The subsidiary objects are to determine the relationship between the value of the extra produce and the dose of manure, and to estimate the optimum dose of manuring with its standard error. The economic aspect of manuring paddy with groundnut-cake has of late been receiving special attention in India. It is proposed to use the data on this subject for illustrating the method. It is, however, necessary to emphasize that there have been very few manurial trials on paddy carried out in the past. The data have been chiefly used for illustration and the conclusions reached in regard to manuring paddy with oil-cake have to be considered to provide indications as such.

The data have been taken from the publications of the Imperial Council of Agricultural Research on manurial experiments on rice conducted in the provinces and states of India during 1932-38 [Vaidyanathan, 1938]. It is possible that there might be some experiments relating to the manuring of paddy with groundnut-cake conducted in the past which have not found a place in the two Imperial Council of Agricultural Research publications. The author would be grateful if details of any such experiments were communicated to him as their consideration, when possible, would doubtless serve to enhance the utility and generality of the conclusions reached in this paper.

Looking through the two volumes on manurial experiments on rice referred to above one is struck by the paucity of the published information relating to replicated field trials on manuring paddy with groundnut-cake. There are to be found just three experiments, one at Maruteru and two at Pattambi in the Madras province which are replicated and which supply valid estimates of error. At Maruteru in the West Godavari District, the experiment was conducted with a departmental variety for three successive years on black deltaic soil. At Pattambi on the west coast the soil was shallow laterite in the two sites on which the experiments were conducted. In one site two crops were raised in each of the two years of the experiment and in the other one crop was raised in a single year. None of the experiments was conducted solely for the purpose of testing the effect of the groundnut-cake in various doses on paddy, but each of them involved the application of other manures as well. Relevant details of these experiments taken from the two volumes are shown in Table I.

A glance at the table shows that with the exception of one trial at Pattambi (crop 1, 1936-37) the mean yields obtained in other trials are of the order of 2,000 lb. per acre. The low mean yield at Pattambi (crop 1, 1936-37) was due to the attack of insect pests in the early stages of the crop and of birds in the later stages. Statistically it appears to fall outside the range to be expected from the remaining group of trials and consequently in a combined review which is attempted here it has been thought advisable to exclude the results of this trial.

Table II shows the absolute and the percentage increases in yields of plots manured with groundnut-cake over plots which did not receive groundnut-cake and the results of the application of the *t*-test of significance at the 5 per cent level. It will be seen from Table II that there is a very good response to the application of groundnut-cake to paddy, the response generally increasing with the increasing dose of manure. The mean percentage response at the dose of 15-16 lb. of N per acre, applied singly or in combination with some other organic manure, works out to be 16. The mean percentage increase is seen to be 31 at the dose from 30 to 32 lb. of N applied singly or in combination and is about 50 when the dose is 48 lb. N per acre. The last but one column shows the significance or otherwise of the increased yields as judged by the *t*-test. At the dose of 15 lb. N per acre the increase in yield secured is not always significant, showing that the dose is slightly inadequate. It is apparent, however, that when the groundnut-cake is applied in quantities to supply a dose of 30-32 lb. N per acre or above, it gives a significantly higher yield than if no groundnut-cake manure was applied.

A significant increase in yield may or may not be accompanied by a significant profit, or, in other words, the value secured for extra crop may or may not significantly exceed the price of manure applied. The significance of profit will depend on the magnitude of the profit secured in relation to its error which in its turn will be determined by the prices obtaining for paddy and manure.

TABLE I

Relevant details of the manurial experiments

No.	Year	Index	Variety	Soil	Details of treatments	Layout	Mean yields of treatments in pounds per acre								Stand-ard error of treat-ment mean	Stand-ard error percent-age
					Pattambi—Madras		Treatments									
I	1936-37	A-I Crop	Ptb-5	Sandy loam	1. Groundnut-cake to supply 30 lb. N	9 × 6 randomized block		1	2	3	4	5	6	7		
	1936-37	B-II ,,	Ptb-3		2. Green leaf 15 lb. N + Groundnut-cake 15 lb. N		A	965	745	841	692	678	973	690	82·09	10·95
					3. Cattle manure 15 lb. N + Groundnut-cake 15 lb. N		B	2159	2005	2051	1706	1660	1937	1690	45·88	2·44
	1937-38	C-I ,,	Ptb-5		4. Green leaf alone to supply 15 lb. N		C	3133	2996	2644	2767	2657	2825	2580	84·94	3·04
		D-II ,,	Ptb-3		5. Cattle manure to supply 15 lb. N		D	1741	1634	1707	1431	1066	1441	1401	92·20	6·22
					6. Groundnut-cake to supply 15 lb. N											
					7. No manure											
II	1937-38	II Crop .	Ptb-3	,,	1. Groundnut-cake to supply 30 lb. N	10 × 6 R. block		1	2							
					2. No manure			2256	1744						34·85	1·47
					Maruteru—Madras											
III	1934-35	A-II Crop	Mth-9	Black cotton soil, Godavari Delta	1. Groundnut-cake to supply 16 lb. N	24 × 7 randomized block		1	2	3	4					
	1935-36	B ,,	Mth-9		2. Groundnut-cake to supply 32 lb. N		A	1895	2061	2372	1478				94·12	3·79
	1936-37	C ,,	Mth-9		3. Groundnut-cake to supply 48 lb. N		B	1774	2004	2059	1462				66·82	3·50
					4. No manure		C	2025	2303	2549	1693				56·28	2·34

TABLE II

Showing significance or otherwise of the extra yield obtained from manuring with groundnut-cake

No.	Cake to supply	Index	Yield in pounds per acre				Critical difference at 5 per cent level of '*t*'	Sig. or not	Remarks
			Cake treatment	Non-cake treatment	Increase	Percentage increase			
Pattambi—Madras									
I(*a*)	15 lb. N .	A	973	690	283	41·0	234·6	Yes	15 lb. N as ground nut-cake (G. C.) over no-manure
		B	1937	1690	247	14·6	131·1	„	
		C	2825	2580	245	9·5	242·7	„	
		D	1441	1401	40	2·9	263·5	No	
(*b*)	15 lb. N .	A	745	692	53	7·7	As above	No	15 lb. N as green leaf + 15 lb. N as G. C. over 15 lb. N as green leaf
		B	2005	1706	299	17·5		Yes	
		C	2996	2767	229	8·3		No	
		D	1634	1431	203	14·2		„	
(*c*)	15 lb. N .	A	841	678	163	24·0	As above	„	15 lb. N as cattle manure+15 lb. N as G. C. over 15 lb. N as cattle manure
		B	2051	1660	391	23·6		Yes	
		C	2644	2657	...	...		No	
		D	1707	1066	641	60·1		Yes	
(*d*)	30 lb. N .	A	965	690	275	39·9	As above	„	30 lb. N as G. C. over no-manure.
		B	2159	1690	469	27·8		„	
		C	3133	2580	553	21·4		„	
		D	1741	1401	340	24·3		„	
II	30 lb. N .	...	2256	1744	512	29·4	99·2	„	30 lb. N as G. C. over no-manure
Maruteru—Madras									
III(*a*)	16 lb. N .	A	1895	1478	417	28·2	262·9	„	16 lb. N as G. C. over no-manure
		B	1774	1462	312	21·4	186·6	„	
		C	2025	1693	332	19·6	157·2	„	
(*b*)	32 lb. N .	A	2061	1478	583	39·4	As above	„	32 lb. N as G. C. over no-manure
		B	2004	1462	542	37·0		„	
		C	2303	1693	610	36·0		„	
(*c*)	48 lb. N .	A	2372	1478	894	60·5	As above	„	48 lb. N as G. C. over no-manure
		B	2059	1462	597	40·8		„	
		C	2549	1693	856	50·6		„	

For a given price of paddy, the value of yield per plot will be subject to the same experimental errors as the quantity of yield itself, so that if p is the price of paddy per unit weight and u the error variance of yield per plot, the error variance of value per plot will be merely p^2u. The error variance of a treatment mean value will be p^2u/r (r being the number of replications) and that of the difference in mean values of manured plots over non-manured plots and hence that of the profit itself for a fixed price of manure will be $2p^2u/r$. The value of '*t*' will be simply given by the quotient of the profit by its standard error. When *t* will exceed the corresponding 5 per cent value, there would be ground for belief, with the risk of going wrong once in 20, that manuring would more than pay for its cost. The whole validity of the application of the *t*-test follows in fact by regarding the money value of yield rather than quantity as the measurable produce for manuring experiments.

It would be confusing if profit and its errors were to be worked out for each of the several comparisons set out in Table II at each of the different combinations of prices of paddy and of manure likely to prevail. It is in fact unnecessary to do so. Where trials have been repeated over a series of seasons as at Maruteru, it adds to the clarity and precision of the conclusions reached if the results of all the years are combined into a single test of significance. For the three trials at Maruteru this has been done in Table III. The figures in the body of the table represent the average profit in Rs. per acre obtained over the three years from each of the several doses of manure applied and for a variety of prices for paddy and manure shown in the first column and top row of the table. The last column gives the values of the critical difference, being the products of the standard errors of average profits with the 5 per-cent values of *t*. It will be clear that when a profit exceeds its corresponding critical difference, it may be considered statistically significant. Significant profits have been all put in italics in the table.

It will be seen that there is as it were a line running across the table dividing it into two portions, one where it pays to manure, the other where it does not. This is only to be expected; for if the price of manure is high, the price of paddy has to be proportionately higher if manuring is to pay. It will be seen that when the price per lb. of nitrogen in the cake is four annas (which at 7½ per cent recovery corresponds roughly to the price of Rs. 1-8 per maund of cake) manuring may be expected to pay even at the price of Rs. 2 per maund of paddy. For a price of six annas per lb. of N in the cake (which roughly corresponds to Rs. 2-4 a maund of cake) manuring is unlikely to pay at Rs. 2 a maund for paddy but can be expected to pay at prices slightly higher than Rs. 2. For higher prices of manures the price of paddy will be seen to be proportionately higher if manuring is to pay. At ten annas per pound of N in the cake manuring is unlikely to pay even at as high a price as Rs. 3-8 a maund of paddy. At the prices now prevailing namely about Rs. 3 a maund for paddy and Rs. 2 to Rs. 2/8 a maund for groundnut-cake, it appears that manuring with cake may almost certainly be expected to give a profit to the cultivator provided that the conditions obtaining in his farm in regard to soil and cultivation are not very different from those at Maruteru.

The results of the two experiments conducted at Pattambi are summarized in Table IV. The table is divided into three sub-tables. In the first the results of the application of groundnut-cake applied singly are presented. It will be seen that the dose of 15 lb. N is inadequate to give a significant profit even at the price of Rs. 3-8 a maund of paddy and the price of four annas per lb. N in the cake. It appears that paddy requires more of nitrogen in the black deltaic soils of Maruteru than in the laterite shallow soils to fetch a significant profit. The dose of 30 lb. N per acre would almost certainly give a significant profit at about the same prices of paddy and cake

TABLE III

Showing significance or otherwise, at various prices of paddy and manure, of extra yield obtained after deducting for the cost of manure applied

(Experiment conducted at Maruteru 1934-37)

Soil : black cotton

Manure / Price of paddy per maund	Price of groundnutcake to supply unit pound of nitrogen												Standard error of profit.	Critical difference
	At Rs. 0·625			At Rs. 0·500			As Rs. 0·375			At Rs. 0·250				
	Groundnut-cake supplying													
	16 lb.N	32 lb.N	48 lb.N	16 lb.N	32 lb.N	48 lb.N	16 lb.N	32 lb.N	48 lb.N	16 lb.N	32 lb.N	48 lb.N		
Rs. 3·5	5·06	4·63	3·30	7·06	8·63	9·30	9·06	12·63	15·30	11·06	16·63	21·30	2·57	5·15
Rs. 3·0	2·90	1·11	—1·45	4·90	5·11	4·55	6·90	9·11	10·55	8·90	13·11	16·55	2·21	4·41
Rs. 2·5	0·75	—2·41	—6·20	2·74	1·59	—0·20	4·74	5·59	5·80	6·74	9·59	11·80	1·84	3·68
Rs. 2·0	—1·40	—5·93	—10·95	0·58	—1·93	—4·95	2·58	2·07	1·05	4·58	6·07	7·05	1·47	2·94

TABLE IV

Showing significance or otherwise, at various prices of paddy and manure, of extra yield obtained after deducting for the cost of manure applied

(Experiment conducted at Pattambi 1936-38)
Soil : sandy loam

Price of paddy per maund	Manure	Price of groundnut-cake to supply unit pound of nitrogen								Standard error of profit	Critical difference
		At Rs. 0·625		At Rs. 0·500		At Rs. 0·375		At Rs. 0·250			
		Groundnut-cake supplying									
		15 lb. N	30 lb. N	15 lb. N	30 lb. N	15 lb. N	30 lb. N	15 lb. N	30 lb. N		
(a) *For increase over no-manure*											
Rs. 3·5	I	—1·85	0·56	0·03	4·31	1·91	*8·06*	3·79	*11·81*	2·67	5·35
	II		3·03		*6·78*		*10·53*		*14·28*	2·09	4·21
Rs. 3·0	I	—2·93	—2·20	—1·05	1·55	0·83	*5·30*	2·71	*9·05*	2·29	4·59
	II		—0·08		*3·67*		*7·42*		*11·17*	1·80	3·62
Rs. 2·5	I	—4·01	—4·96	—2·13	—1·21	—0·25	2·54	1·63	*6·29*	1·91	3·82
	II		—3·19		0·56		*4·31*		*8·06*	1·50	3·01
Rs. 2·0	I	—5·09	—7·72	—3·21	—3·97	—1·33	—0·22	0·55	*3·53*	1·53	3·06
	II		—6·30		—2·55		1·20		*4·95*	1·20	2·41
(b) *For increase over 15 lb. N as green leaf*											
Rs. 3·5		1·00	...	2·88	...	4·76	...	*6·64*	...	2·67	5·35
Rs. 3·0		—0·48	...	1·40	...	3·28	...	*5·16*	...	2·29	4·59
Rs. 2·5		—1·96	...	—0·08	...	1·80	...	3·68	...	1·91	3·82
Rs. 2·0		—3·44	...	—1·56	...	0·32	...	2·20	...	1·53	3·06
(c) *For increase over 15 lb. N as cattle manure*											
Rs. 3·5		5·08	...	*6·96*	...	*8·84*	...	*10·72*	...	2·67	5·35
Rs. 3·0		3·02	...	*4·90*	...	*6·78*	...	*8·66*	...	2·29	4·59
Rs. 2·5		0·96	...	2·84	...	*4·72*	...	*6·60*	...	1·91	3·82
Rs. 2·0		—1·10	...	0·78	...	2·66	...	*4·54*	...	1·53	3·06

as found at Maruteru. Table IV (*b*) shows that groundnut-cake to supply 15 lb. N per acre is adequate to return a profit if applied in combination with cattle manure, in roughly the same range of prices as at Maruteru. It will thus be seen that while the effect of cattle manure is beneficial, that of green-leaf is not as seen from Table IV (*c*).

Figs. 1-4 represent the results summarized in Table III of the three years experiment at Maruteru. The four diagrams (Figs. 1-4) correspond to the four rates of paddy. The amount of nitrogen as groundnut-cake applied per acre is plotted along the horizontal axis, and the value of extra crop and of manure applied are plotted along the vertical axis. The continuous curve represents the average value of the extra crop raised against the dose of manure applied. The four straight lines give the cost of manure applied at the rates shown beside them. The dotted curve gives the values of extra produce minus the critical errors at the 5 per cent level of *t*. For convenience this curve may be called the lower fiducial curve of the values of extra produce at the 5 per cent level of *t*.

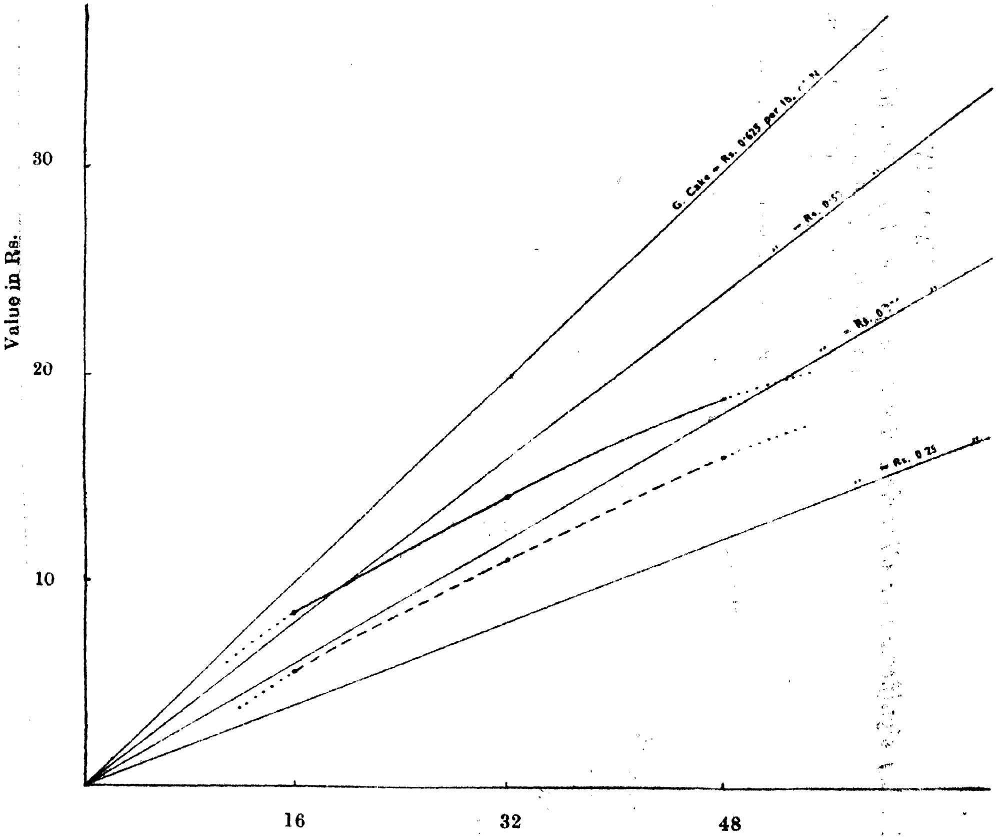

FIG. 1 Price of paddy Rs. 2 per maund

The diagrams are self-explanatory and can be read without any difficulty. It is obvious that if the value of the ordinate of the dotted curve is more than the value of the ordinate of the cost line for manure, manuring may be expected to pay for the dose applied, e.g. in Fig. 3 within the range of doses tried the dotted curve lies wholly above the cost line for manure corresponding to the rate of eight annas per lb. of N in the cake. This shows that at the price of Rs. 3 per maund of paddy manuring in the range from 16 lb. N to 48 lb. N per acre may be expected to pay up to the rate of eight annas per lb. of N in the cake.

The precise determination of the optimum dose of manuring implied in the subsidiary question regarding manuring presupposes a known form of relationship between the value of extra produce and the dose of manure applied. Field experiments rarely include more than three to four doses of manuring,

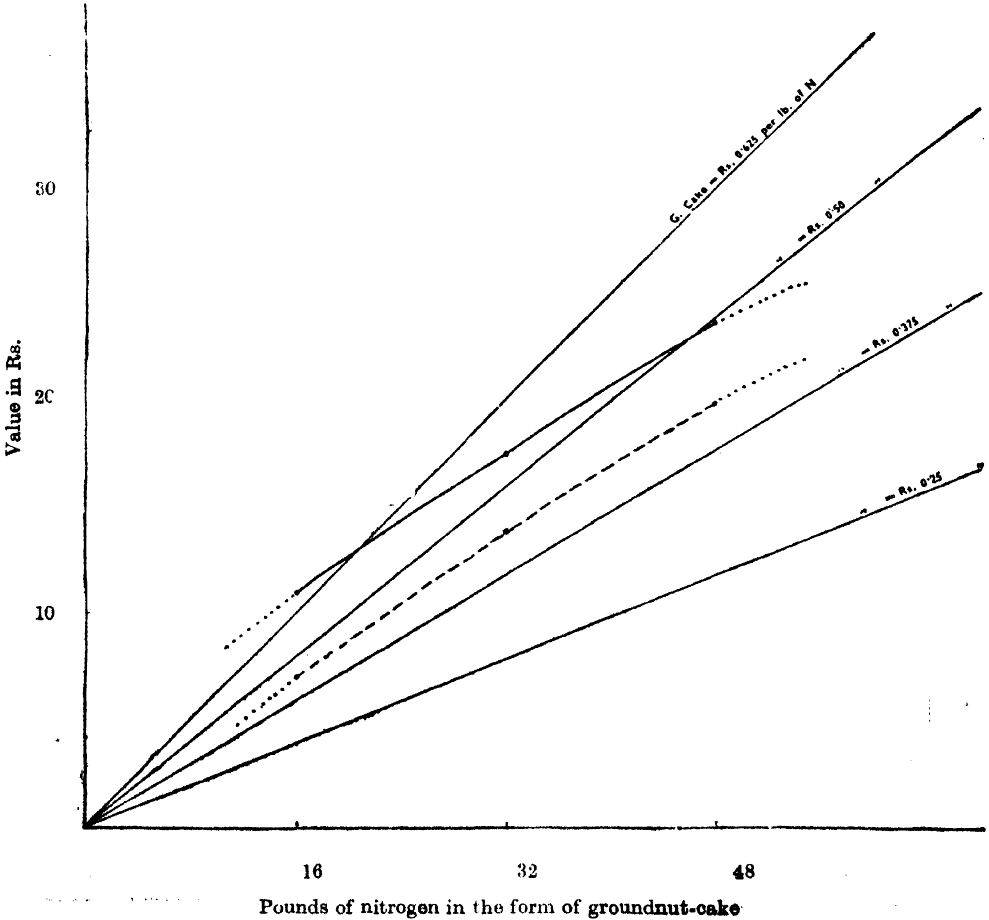

FIG. 2 Price of paddy Rs. 2-8 per maund

which are clearly too few to provide an adequate indication of this relationship. It would, however, appear reasonable to assume that a second degree parabola of the form $v = \alpha + \beta d + \gamma d^2$, where v denotes money value and d the dose of manure, would adequately represent the relation. Its shape would be as shown in the four diagrams with concavity facing the horizontal axis. It is a curve often used to represent the relation in question and is clearly the one that commonsense and facts support. Thus Andrews [1940] has recently used it in his paper on the elimination of differences in investment in the evaluation of the fertilizer analyses. The equation to the straight line giving the cost of manure is clearly $v = qd$, where q is the price per unit dose of manure. It will be readily seen that the optimum dose is given by the point where the tangent to the value curve is parallel to the cost line for manure. In the notation used above the optimum dose $\hat{d}$ is given by $\frac{q-\beta}{2\gamma}$.

In the experiment at Maruteru the manure was applied in only three doses, the corresponding average extra yields and values of produce being those shown on the next page:—

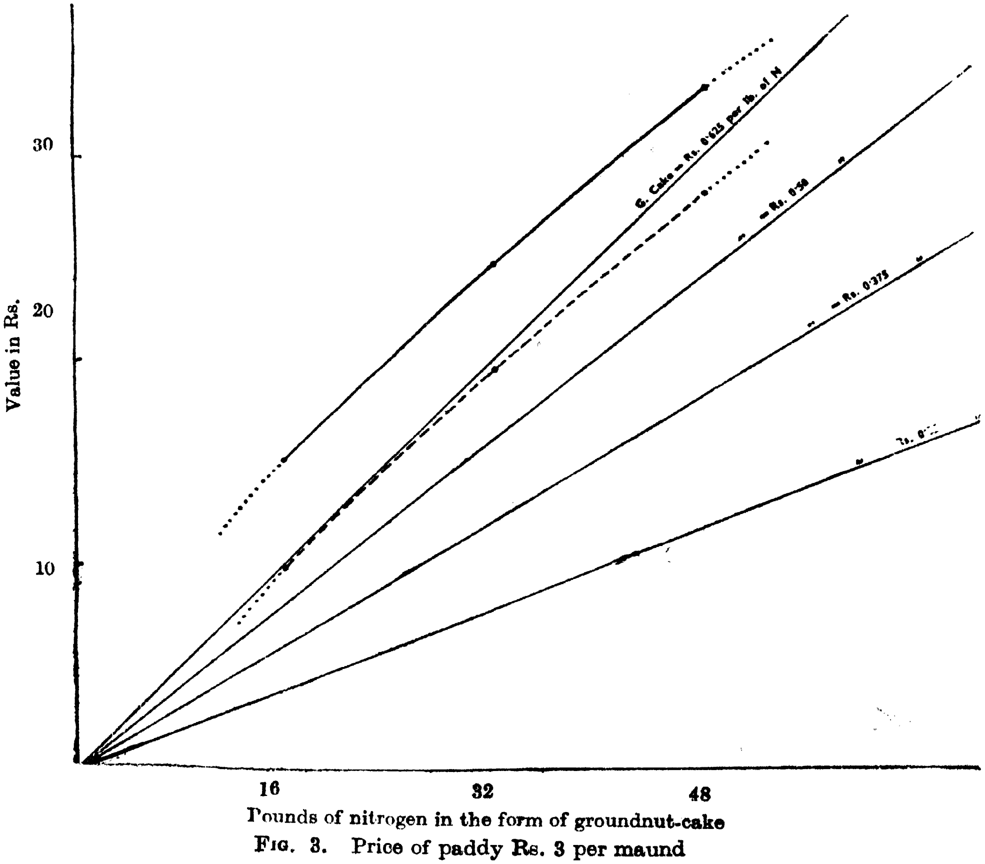

FIG. 3. Price of paddy Rs. 3 per maund

Dose of manure (in units of 16 lb. of N in the cake)	Average extra yields in lb.	Value in Rs. of extra produce at rates per maund			
		Rs. A. 3 8	Rs. A. 3 0	Rs. A. 2 8	Rs. A. 2 0
1	354	15·0565	12·9056	10·7546	8·6037
2	579	24·6263	21·1083	17·5902	14·0722
3	783	33·3030	28·5484	23·7878	19·0303

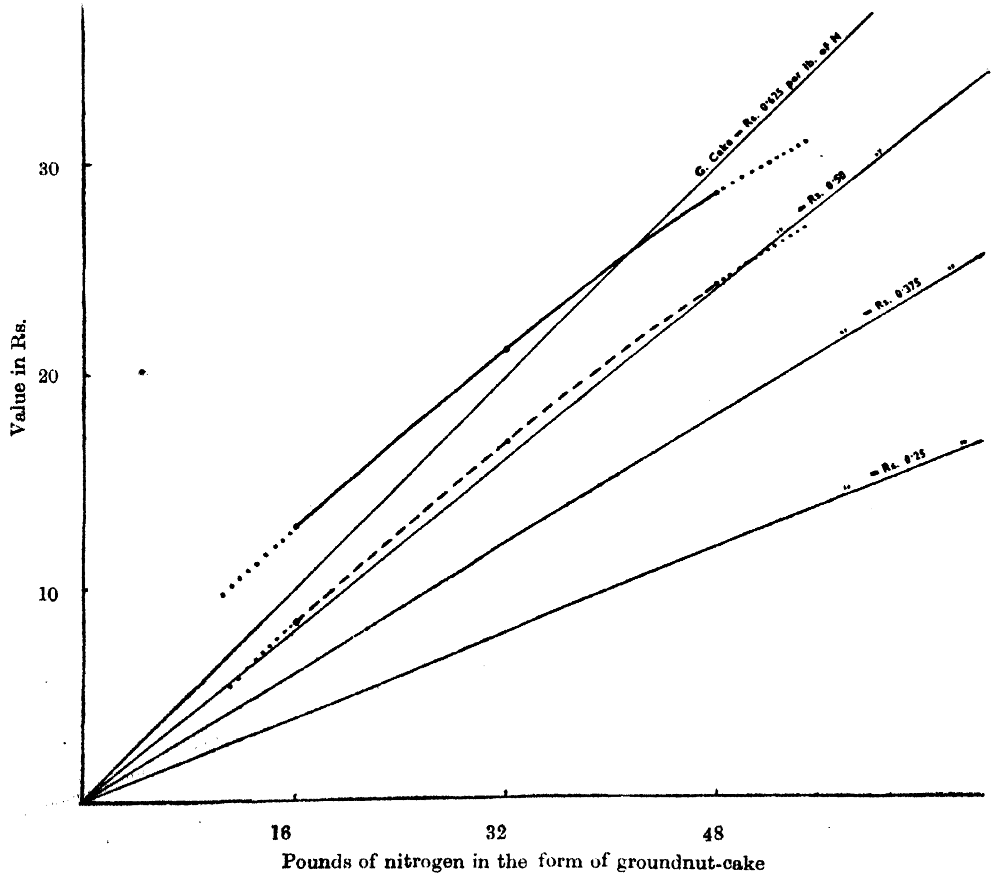

FIG. 4. Price of paddy Rs. 3-8 per maund

The four equations to the parabolas corresponding to the four rates of paddy representing the value in rupees of the average extra produce in terms of the dose of manure in lb. of N applied are readily found to be :—

Price of paddy per maund	
Rs. 3-8	$v = 4{\cdot}5935 + 10{\cdot}9088\,d - 2{\cdot}4465\,d^2$
Rs. 3	$v = 3{\cdot}9373 + 9{\cdot}3504\,d - 0{\cdot}3827\,d^2$
Rs. 2-8	$v = 3{\cdot}2811 + 7{\cdot}7920\,d - 0{\cdot}3190\,d^2$
Rs. 2	$v = 2{\cdot}6249 + 6{\cdot}2336\,d - 0{\cdot}2552\,d^2$

The values for the optimum dose of manure are obtained by substituting in the formula for $\hat{d}$ values for q, β and γ, e.g. at the prices of Rs. 3 per maund of paddy and Rs. 8 per 16 lb. of N in the cake, the optimum dose in units of 16 lb. of N will be $\frac{8-9{\cdot}3504}{-2\times 0{\cdot}3827}$.
or 1·764 which is equivalent to the dose of 28·2 lb. of nitrogen in the cake. Values for the optimum dose corresponding to other combinations of prices of paddy and manure can be similarly obtained. These have not been, however, tabulated in the paper as they are mostly found to lie outside the range of doses included in the experiments. They serve to indicate the necessity for including higher doses in future trials, but beyond that not much value can be placed on them. They are moreover subject to very large sampling errors. The derivation of the formulæ for the standard error of the optimum dose and of the profit to be expected at any dose desired to be applied together with its standard error is briefly outlined in the Appendix.

REFERENCES

Andrews, W. B. (1940). *J. Amer. Soc. Agron.* **32**, 495

Burns, W. (1940). *Indian Farming* **1**, 365-8

Sukhatme, P. V. (1941). *Current Sci.* **10**, 214

Vaidyanathan, M. (1932-38). *Analysis of manurial experiments in India* : 1932-38 I. C. A. R.

APPENDIX

The equation to the value curve can be alternatively put in the form

$$v=\bar{v}+b_1\,\varepsilon_1+b_2\,\varepsilon_2$$

where v is the average of the observed values, ε_1 and ε_2 are the orthogonal functions of d given by $\varepsilon_1 = d - \bar{d}$; $\varepsilon_2 = \varepsilon_1^2 - \frac{n^2{}_1-1}{12}$

and b_1 and b_2 are constants given by the usual formulæ, namely

$$b_1 = \frac{S\,(\varepsilon_1\ v)}{S\,(\varepsilon_1^2)}$$

and $b_2 = \frac{S\,(\varepsilon_2\ v)}{S\,(\varepsilon_2^2)}$

It will be clear that γ_2 is identical with b_2 and $\beta = b_1 - 2\,\bar{d}\,b_2$. The variances of b_1 and b_2 are clearly independent of each other, being given by

$$V(b_1) = \frac{\sigma^2}{S\ (\varepsilon_1^2)}$$

$$V(b_2) = \frac{\sigma^2}{S\ (\varepsilon_2^2)}$$

where σ^2 is the variance of v. The variance of the optimum dose is clearly the variance of $\frac{q-b_1}{2b_2}$. On differentiating and squaring it will be found to be

$$\frac{\sigma^2}{b_2^2}\left\{\frac{(\hat{d}-\bar{d})^2}{S\ (\varepsilon_2^2)} + \frac{1}{4}\,\frac{1}{S\ (\varepsilon_1^2)}\right\}$$

The profit to be expected for any given dose of manure is clearly given by the ordinate of the value curve. It follows from what has been given above that its variance is simply the variance of mean $\bar{v}$ *plus* the quantity

$$\sigma^2\left\{\frac{\varepsilon_1^2}{S\ (\varepsilon_1^2)} + \frac{\varepsilon_2^2}{S\ (\varepsilon_2^2)}\right\}$$

SOIL UNIFORMITY TRIALS IN THE PUNJAB, II

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DURING recent years a number of fertility trials have been carried out at various agricultural stations in the Punjab. In the first paper of the series [Lander, Narain and Singh, 1938] the data relating to four soil uniformity test crops grown at the Rawalpindi Agricultural Station were presented. One of the more important conclusions arrived at was the recognition of the fact that soil heterogeneity may be of two types—casual and permanent—and that while the former may vary with the crop and the season, the latter is independent of such factors, and maintains its level under all conditions.

The effects of these permanent differences in the soil fertility of any piece of land can be eliminated by adopting a suitable form of layout which takes into consideration variations in soil fertility of different portions of the land in question. It has been observed, however, that in a number of cases, even after eliminating the effects of these fertility differences, there may still remain differences between the individual plots within a block, which, although due to casual factors, are sometimes responsible for large errors in the experiment. The method of covariance attempts to evaluate the effect of these casual factors when they persist for more than one season.

A study of the literature on this subject shows that very useful results have been obtained by the application of the method of covariance to data from perennial crops. Of late, considerable stress has been laid on the importance of growing soil fertility crops* and very often suggestions have been put forward that in case the relative yields of plots are maintained during succeeding seasons, the application of this method should prove useful in bringing about an appreciable reduction in error even in the case of annual crops. Sanders [1930] was probably the first to take up Fisher's original suggestion and apply the method to data from such crops. The usefulness of the method has subsequently been tested by a number of workers, viz. Verteuil [1934], Summerby [1934], Vaidyanathan [1934], Love [1936], Lander, Narain and Singh [1938] and others. It will be recognized, however, that the data examined

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*In this connection reference may be made to the comprehensive list of papers on uniformity trials published by Cochran [1937] under the title *Catalogue of uniformity trial data.*

by most of the above authors are not sufficient to allow of a definite conclusion being arrived at about the usefulness of the method of covariance in the study of annual crops, but, as has been mentioned in the previous paper of this series, considerable data from fertility trials carried out at various agricultural stations in the Punjab are available, which could be used to examine exhaustively the usefulness of the application of the method of covariance in increasing the precision of results obtained from annual crops.

EXPERIMENTAL MATERIAL

The following table shows the names of stations and of crops grown together with the size of plots and the seasons of growth

Name of station	Plot size (acres)	Crops and years						Remarks
		1929		1930		1931		
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	
Sargodha . . .	1/10		Wheat*	Maize**	Wheat			Div. A
			Wheat	*Chari*†	Wheat			,, B
		Chari†	Wheat		Wheat			,, C
			Wheat	*Chari*	Wheat			,, D
		Chari	Wheat		Wheat			,, E
Montgomery . .	1/13		Wheat (1932-33)		Wheat (1933-34)	*Chari* (1934)		Sq. 17 Div. A, B, C & D
					Wheat (1931-32)	*Chari* (1932)		Sq. 28 Div. A, B, C & D
Karor . . .	1/20			*Chari*	Wheat		Wheat	
Lyallpur . . .	2/9	*Chari*	Wheat	*Chari*				
Gurdaspur . .	1/10	*Chari*	Gram	*Chari*				
Hansi . . .	1/10			*Chari*		*Chari*		Div. A & B

**Triticum vulgare*
***Zea mays*
†*Andropogon Sorghum*

EXAMINATION OF DATA FROM UNIFORMITY TRIALS

In the previous paper, the data from the Rawalpindi Agricultural Station were examined in half a dozen different ways with the object not only of studying soil heterogeneity of the land under trial but also of ascertaining how far the method of covariance could be usefully employed in increasing the precision of the experiment in the case of annual crops. In the present paper, only the coefficients of variation of different blocks have been used as an index of soil heterogeneity. The analyses of variance and covariance have been employed to study the standard error per plot and also to measure the extent to which the precision of the experiment can be increased by a consideration of the data obtained from previous crops.

As has been explained in the first paper of the series, the adjusted variance of the supposed experimental crops can be calculated according to Sanders' [1930] formula.

$$V_{yx} = \left(V_y - \frac{(Cov\ xy)^2}{V_x} \right) \frac{n}{n-1}$$

where x stands for preliminary yields, y for subsequent yields, *Cov* for covariance and Vyx for variance of y corrected for x. The values for adjusted variances thus obtained have been given in relevant tables. If, however, data of two or more previous crops are available the adujstment necessitates a simultaneous correction for regression of the yields of final crop on those of the previous ones. One of the methods suggested by Sanders [1930] and applied subsequently by Summerby [1934] and Love [1936] is to obtain the average of the yields of each plot in different years expressed as a percentage of their respective mean. These figures are then employed for the analysis of the experimental crop. There is, however, another method suggested by Brady [1935] according to which it is necessary to form a new regression equation which is based on two or more variables as the case may be. As an illustration of the use of this method the various steps leading to the evaluation of the results are discussed in some detail with reference to the yield data from division A at Sargodha given below :—

Yields (mds. per acre) for the three test crops from division A at Sargodha

Block I			Block 2			Block 3			Block 4		
Wheat 1929-30	Maize 1930	Wheat 1930-31	Wheat 1929-30	Maize 1930	Wheat 1930-31	Wheat 1929-30	Maize 1930	Wheat 1930-31	Wheat 1929-30	Maize 1930	Wheat 1930-31
45·5	85·3	14·3	57·0	71·0	24·3	66·0	82·3	76·5	64·0	121·0	47·0
44·3	84·0	14·5	51·8	46·8	25·8	70·8	169·0	51·5	63·3	109·5	49·5
49·5	90·3	16·8	64·3	82·5	20·0	77·8	184·0	46·8	63·5	115·8	46·0
59·0	85·5	18·8	62·0	88·3	17·5	72·5	162·0	52·0	69·0	136·0	54·3
56·5	82·8	13·8	66·0	88·5	24·3	75·8	125·3	38·5	65·5	139·0	45·0
50·3	79·0	15·8	58·8	83·5	40·3	67·5	99·3	43·5	68·0	135·8	52·8
52·5	81·3	19·8	49·5	76·3	37·5	71·8	115·5	37·8	70·5	160·3	67·8
60·5	73·5	18·3	46·0	87·8	39·0	63·3	99·0	70·8	80·3	144·0	52·3

The analyses of variance and covariance for this division are given below :—

Analyses of variance and covariance for different crops (Sargodha)

Division	Description	Source of variation	Degrees of freedom	Sum of squares	Variance	Test crops	Sum of products	Covariance
A .	I Wheat 1929-30 .	Between blocks	3	1857·55	...	I × II	5866·92	...
		Within blocks	28	1009·75	36·06		—1541·69	55·06
	II Maize 1930 . .	Between blocks	3	20698·69	...	II × III	11722·80	...
		Within blocks	28	13343·37	476·55		—845·55	—30·20
	III Wheat 1930-31 .	Between blocks	3	7525·04	...	I × III	3706·12	...
		Within blocks	28	2410·95	86·11		—478·24	—17·08

From the figures given above, the two regression coefficients b_1 and b_2 can be easily calculated with the help of the following equations :—

$$b_1 = \frac{(Vx_2 \times Cov\ x_1y) - (Cov\ x_1x_2 \times Cov\ x_2y)}{Vx_1 \times Vx_2 - (Cov\ x_1\ x_2)^2} \quad \text{and}$$

$$b_2 = \frac{(Vx_1 \times Cov\ x_2y) - (Cov\ x_1x_2 \times Cov\ x_1y)}{Vx_1 \times Vx_2 - (Cov\ x_1\ x_2)^2}$$

where x_1, x_2 and y stand for the first, the second and the third crop respectively. The values for b_1 and b_2 obtained by substituting the values given in the statement of analyses of variance and covariance above work out to :

$b_1 = -0{\cdot}4576$ and
$b_2 = -0{\cdot}0105$

Using these values the variance of adjusted yields in any line in the analysis of variance can be readily obtained by applying the following formula :

$$Vyx_1x_2 = \left\{ Vy - b_1\ (Cov\ x_1y) - b_2\ (Cov\ x_2y) \right\} \frac{n}{n-2}$$

where Vyx_1x_2 is the adjusted variance of the final crop. Substituting the necessary figures in the above formula we obtain

$$Vyx_1x_2 = \left\{ 86{\cdot}11 - (-0{\cdot}4576 \times -17{\cdot}08) - (-0{\cdot}0105 \times -30{\cdot}20) \right\} \times \frac{28}{26}$$
$$= 83{\cdot}98$$

It is to be noted that as two degrees of freedom have been used for calculating the two regression constants b_1 and b_2, the degrees of freedom corresponding to error have to be diminished by 2, leaving in the example cited above only 26 degrees of freedom ascribable to error. Thus the figure for adjusted variance will be 83·98. This change of variance for the third crop from 86·11 to 83·98 indicates that there has been a small increase in the relative precision of the result to the extent of $\frac{86{\cdot}11}{83{\cdot}98}$ or 1·0255. The percentage gain in precision will therefore be $(1{\cdot}0255 \times 100) - 100$ or 2·55. The increase in the accuracy of the experiment is thus only very slight and inappreciable.

The above discussion illustrates how the method of covariance can be applied to adjust the yields of the experimental crop when yield data of three or more crops are available.

As the values of the two regression coefficients b_1 and b_2 have been calculated from the variance and covariance of the three crops, the variance for the adjusted yields in any line in the analysis of variance can be directly worked out by substituting, in the following formula, the corresponding values given in the statement of analyses of variance and covariance already given :—

$$Vyx_1\ x_2 = \left\{ Vy - \frac{(Cov\ x_1y)^2\ Vx_2 - (Cov\ x_2\ y)^2\ Vx_1 - 2\ (Cov\ x_1\ x_2)\ (Cov\ x_1\ y)\ (Cov\ x_2\ y)}{Vx_1\ Vx_2 - (Cov\ x_1\ x_2)^2} \right\} \frac{n}{n-2}$$

It will be seen that in applying the above equation for obtaining the variance of the adujsted yields, the need of calculating the regression coefficients is eliminated. The evaluation of these figures, however, and their use as explained already, supply a useful check on the accuracy of the arithmetic employed.

As different crops were grown at various stations during any one season and under different soil and climate conditions, it is proposed to examine the results for each station separately.

SARGODHA

It will be seen from the statement already given that the trials at Sargodha were carried out in five divisions, each consisting of four blocks of eight plots. The mean yield and coefficients of variation for each block in different sub-divisions are given in Table I.

It will be observed that the yield of wheat following maize or *chari*, with one or two exceptions, is invariably lower than the yield of wheat either preceding any of these two crops or following wheat as in divisions C and E. In other words the yield of wheat following a *kharif* fallow is invariably higher than that which is obtained after a *kharif* crop of maize or *chari*.

Considering the coefficients of variation, it is found that in the case of wheat a high coefficient of variation is generally associated with low mean yields. The wide differences obtained in the values of this constant indicate the lack of any constancy in the fertility of the plots within each block of any division.

The analyses of variance and covariance for different crops grown in each division are given in Table II, which also gives the percentage standard error, regression coefficients, adjusted variance, relative precision of results and the percentage gain in precision resulting from the application of the method of simple and multiple covariance.

The percentage standard errors (Table II) per acre, even after the elimination of soil-fertility differences are sufficiently high, and in the case of the three crops, viz. wheat 1930-31 (A), wheat 1929-30 (C), and *chari* 1929(E), they are much higher than can normally be allowed in field experiments.

The figures for percentage gain in precision obtained by considering different crops vary within wide limits, the values being positive in the case of some crops and negative in that of others. In division D, although all the four values are positive, yet the extent of variation in these values is by no means small. Considering all the divisions, the variation in these values indicates that the anticipated gain in precision is very uncertain, so much so that a loss in precision was recorded in five cases out of a total of 20 examined. Even the application of multiple covariance conferred no special advantage.

MONTGOMERY

The trials at Montgomery were conducted on two pieces of land in squares 17 and 28. There were four divisions in each square, the crops in sq. 17 being wheat-wheat-*chari*, while in square 28 they were wheat and *chari*. The results from these two pieces of land are presented and discussed separately.

Square 17.—The data relating to this piece of land are presented in Tables III and IV. Considering the mean yields of wheat in all the divisions it will be observed that these are higher in the case of the 1932-33 crops than those obtained during the succeeding year. In all cases except two, the high yields are associated with a low coefficient of variation, and *vice versa*. It may further be noted that the yields of wheat in 1933-34, due to very late sowing, are exceptionally low in all the blocks in all the divisions. In the year 1932-33, division

C gave the highest yield of all, otherwise there seems to be a definite fertility gradient from divisions A to D. This is also apparent when we consider the mean yields of wheat in the succeeding year in all the divisions. This fertility gradient, however, is not noticeable when the yields of *chari* in 1934 are considered. Figures for percentage standard errors given in Table IV confirm the conclusion that, in a majority of cases, high standard errors are associated with low mean yields, and *vice versa*. The figures for percentage gain or loss of precision given in the same table corroborate the conclusions drawn from trials at other stations, viz. that there is no appreciable gain in precision by adjusting the yields of an experimental crop with reference to those of the previous non-experimental ones. In the present case when the yields of crop II in division A are corrected for those of crop I, there is a gain in precision of 43 per cent, but this gain in precision in divisions B, C and D comes to only 7, 11 and 3 per cent respectively, which is not commensurate with the time, labour and expense involved in conducting fertility trials. In none of the remaining cases is there any gain in precision except in the case of the crop III in division A when its yield is corrected with reference to that of crop II, but this gain in precision is nominal and inappreciable, being only 0·45 per cent.

Square 28.—The yields of wheat obtained from this piece of land were very high and almost equal to those for the succeeding *chari* crop (Table V). The coefficients of variation for wheat in different divisions vary between 2 and 11·5 and therefore the standard error for this crop (Table VI) which varies between 4·41 and 8·06 is one of the lowest found during these trials anywhere. Similarly, the coefficients of variation for the succeeding *chari* crop, although higher than those of wheat, are fairly uniform in different divisions. Considering the results for relative precision it seems that except for division A, the percentage gain in precision, when the yields of crop II are corrected for those of crop I, is positive in all cases, being about 12 per cent in division C and 29 per cent in divisions B and D. These positive figures, however, are of no practical significance.

KAROR (MUZAFFARGARH DISTRICT)

At this place three crops were grown in six blocks of six plots each. The mean yields and coefficients of variation are given in Table VII, and it will be seen that here also the yield of wheat following a *kharif* fallow is much higher than that following a *chari* crop during *kharif*. The coefficients of variation in the case of wheat in five cases out of six are greater where the yields are low. Analyses of variance and covariance and the figures for relative gain in precision are given in Table VIII. It will be seen here that not only is there no uniformity in the figures for gain in precision, but even the extent of this gain indicated by positive figures in this table is very small.

LYALLPUR

The data for this station are presented in Tables IX and X. The values for coefficients of variation in all the blocks at this station vary between 6 and 23 except in the case of the last two crops, viz. wheat and *chari* in block 1. In block 1 the figures for wheat and *chari* are as high as 40 and 37 respectively. The standard error for the two *chari* crops is nearly 13, while for wheat it is 17. The values for percentage gain in precision resulting after adjustment of the yields of crop III on the basis of those of crop II, and crops I and II taken together, are very high, the relative precision being more than double.

GURDASPUR

The data for this station are presented in Tables XI and XII. One peculiar feature of these trials was that a legume crop, viz. gram, intervened between the two *kharif* crops of *chari*, and the coefficients of variation for the gram crop, in five cases out of six, are the highest. Even the percentage standard error for this crop (Table XII) is more than two to three times that of *chari*. It was expected that yields of *chari* after gram would benefit by fixation of nitrogen brought about by the latter crop, but these yields, following the gram crop, were invariably lower than the yields from the *chari* crop preceding it. This may be due to seasonal factors which, during the two months that the land remained fallow, might have exercised an adverse effect on the conservation of nitrogen brought about by the previous crop.

No practical gain in precision resulted in any case by the application of the method of covariance.

HANSI

The two crops for which data at this station are available were both *chari*. The yields of the second crop in both the divisions (Table XIII) which followed a *rabi* fallow were lower than those of the first crop. This shows that the intervening fallow has not been able to raise the standard of fertility to its original level, and to raise *chari* after *chari* without manuring is not likely to be an economic proposition. The standard errors for the four crops (Table XIV) in the two divisions vary between 11 and 13 and are of the lowest. There has been no gain in precision in division A by the application of covariance, while division B shows a gain of about 50 per cent.

CONCLUSIONS

Before drawing any general conclusions from the data presented above, attention must be drawn to the high standard errors generally met with in the yield from these experiments. Except in the case of division B at Sargodha where the standard error varies between 6·8 and 13·6 and of all the four divisions in square 28 at Montgomery where this variation lies between 4·4 and 12·4 and at Hansi with figures less than 13, the standard errors in the remaining cases are not only very high but also show wide variations even in the same division. For example, in the case of division C at Sargodha, the error varies between 9·5 and 32·1 and at Montgomery in square 17, division B the variation is between 15·7 and 52·7. Similarly at Gurdaspur the variations are between 8·5 and 29·0. These high figures seem to indicate a high degree of soil heterogeneity or a low standard of cultivation or both.

During the examination of the data it was found that the variance due to ' between block ' was invariably many times greater than that due to within blocks, thereby showing that the forms of layout adopted were efficient. From theoretical considerations, it would seem that an increase in the size of blocks would bring about an increase in error, since under these conditions, the elimination of fertility differences due to blocks will not be adequate. In these trials blocks of different sizes varying from 0·3 to 1·5 acres were employed at different places. However, no consistent relationship between the size of the block and the error per plot is noticeable. For instance, at the Montgomery Agricultural Station, the size of the blocks in square 28 is only slightly greater than that in square 17, and yet in the former case, the standard error per plot is much higher than that obtained in the latter case. Similarly, in division B at Hansi, the block size is 9/10 of an acre as against 8/10 of an acre at Sargodha, but the standard error per plot is much higher in the latter case. At Lyallpur and Karor also the standard errors are of the same order although the size of the blocks at Lyallpur is five times the size of those at Karor.

Considering the increase in precision resulting from the application of the method of covariance, it will be seen that in all 54 cases have been examined ; 42 of these are of simple covariance where the yields of a crop are adjusted according to the yields of one previous crop and the remaining 12 are cases of multiple covariance where the yields of the third crop are adjusted with reference to those of the first and second conjointly. Of the 42 cases of covariance, positive values have been obtained in 23 cases and negative in 19. Of these 23 positive values, however, the gain in precision can be said to be appreciable only in four cases, the actual figures for such percentage gain being 91, 115, 113 and 49, which cannot be regarded as commensurate with the time and labour spent. Of the 12 cases of multiple covariance 7 are positive, and of these only three gave appreciable increase in precision, the actual figures being 53, 106 and 115.

The data presented in this paper demonstrate conclusively that no useful gain in precision is likely to result by conducting a preliminary uniformity trial. The results obtained further show that the value for the gain in precision obtained by the application of simple covariance is not likely to be enhanced if, instead of one, two uniformity crops are taken. The time and labour spent in raising these crops during a uniformity trial are thus in no way justified. Consequently on grounds of precision alone, the conduct of preliminary trials in the case of annual crops cannot be recommended. The fact that these delay the experimental results by at least one year is an additional argument against such trials.

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REFERENCES

Brady, J. (1935). *Supplement to J. Roy. Stat. Soc.* **2**, 103
Cochran, W. G. (1937). *Supplement to J. Roy. Stat. Soc.* **4**, 233
De Verteuil, J. (1934). *J. Trop. Agric.* **11**, 315
Lander, P. E. ; Narain, R. and Singh, A. (1938). *Ind. J. Agric. Sci.* **8**, 271
Love, H. (1936). *J. Amer. Soc. Agron.* **28**, 234
Sanders, H. G. (1930). *J. Agric. Sci.* **20**, 63
Summerby, R. (1934). *Macdonald College (McGill University) Tech. Bull. No.* **15**
Vaidyanathan, M. (1934). *Ind. J. Agric. Sci.* **4**, 327

TABLE I

Mean yield in mds. per acre and coefficient of variation of each block in different years (Sargodha)

Division	Crop and year	Blocks								Remarks
		1		2		3		4		
		Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
A . .	**Wheat** 1929-30	52·3	11·47	57·1	11·68	70·2	6·98	68·0	8·43	**4 blocks of 8 plots each**
	Maize 1930	32·7	6·03	78·1	18·03	129·6	28·98	132·7	12·44	
	Wheat 1930-31	16·5	14·49	28·6	31·43	52·2	27·45	51·8	14·07	
B . .	**Wheat** 1929-30	42·0	17·43	46·0	14·33	59·6	12·74	51·6	10·16	
	Chari 1930	148·6	8·39	157·9	14·42	241·5	9·94	194·0	11·45	
	Wheat 1930-31	16·5	13·76	28·6	31·43	52·2	26·88	51·8	14·01	
C . .	***Chari*** 1929	134·8	3·02	130·1	12·91	78·5	14·04	81·0	11·88	
	Wheat 1929-30	29·1	12·10	42·3	36·03	14·0	11·86	12·9	11·32	
	Wheat 1930-31	70·3	10·01	53·9	5·36	68·3	11·88	67·9	8·06	
D . .	**Wheat** 1929-30	101·5	6·12	86·1	5·64	111·3	11·34	94·3	11·98	
	Chari 1930	83·7	9·43	88·3	18·20	101·8	19·72	96·3	14·64	
	Wheat 1930-31	8·6	3·60	8·9	4·72	13·5	18·15	12·6	8·97	
E . .	***Chari*** 1929	89·0	25·83	122·8	33·50	124·4	9·70	114·9	12·85	
	Wheat 1929-30	15·5	13·29	13·4	16·79	12·6	7·62	11·1	17·57	
	Wheat 1930-31	39·9	20·07	52·4	11·22	83·8	11·92	65·2	17·33	

TABLE II

Analyses of variance and covariance for different crops (Sargodha)

Division	Due to	Analysis of original yields					Adjustment by covariance			
		Degrees of freedom	Crops				II Corrected for I	III Corrected for II	III Corrected for I	III Corrected for I & II
			Wheat 1929-30 I	Maize 1930 II	Wheat 1930-31 III					
			Mean sq.	Mean sq.	Mean sq.	Coefficient of regression (*b*) .	+1·5270	—0·0634	—0·4737	b_1 = —0·4576 b_2 = —0·0105
	Error	28	36·06	476·55	86·11	Adjusted variance . .	407·00	87·31	80·90	83·98
			Covariance I × II	Covariance II × III	Covariance I × III					
A . .	Error	28	+55·06	—30·20	—17·08	Relative precision . .	1·1710	0·9862	1·0643	1·0255
	Percentage standard error		9·69	20·63	24·88	Percentage gain or loss of precision	+17·10	—1·38	+6·43	+2·55
			Wheat 1929-30 I	*Chari* 1930 II	Wheat 1930-31 III	Coefficient of regression (*b*) .	—0·1688	+0·0598	+0·1321	b_1 = +0·1428 b_2 = +0·0623
	Error	28	Mean sq. 45·86	Mean sq. 440·49	Mean sq. 6·31	Adjusted variance . .	455·43	4·92	5·71	4·10
			Covariance I × II	Covariance II × III	Covariance I × III					
B . .	Error	28	—7·74	+26·33	+6·06	Relative precision . .	0·9671	1·2825	1·1051	1·5337
	Percentage standard error		13·59	11·32	6·84	Percentage gain or loss of precision	—3·29	+28·25	+10·51	+53·78
			Chari 1929 I	Wheat 1929-30 II	Wheat 1930-31 III	Coefficient of regression (*b*) .	+0·9255	+0·1120	+0·2369	b_1 = +0·2311 b_2 = +0·0632
	Error	28	Mean sq. 142·50	Mean sq. 62·40	Mean sq. 38·33	Adjusted variance .	63·44	38·94	31·45	32·40

TABLE II—*contd.*

Division	Due to	Analysis of original yields					Adjustment by covariance			
		Degrees of freedom	Crops				II Corrected for I	III Corrected for II	III Corrected for I	III Corrected for I & II
			Covariance I×II	Covariance II×III	Covariance I×III					
C	Error	28	+13·19	+6·99	+33·76	Relative precision	0·9836	0·9843	1·2188	1·1830
	Percentage standard error		11·25	32·11	9·49	Percentage gain or loss of precision	—1·64	—1·57	+21·88	+18·30
			Wheat 1929-30 I Mean sq.	*Chari* 1930 II Mean sq.	Wheat 1930-31 III Mean sq.	Coefficient of regression (*b*)	+1·1495	+0·0108	+0·0924	b_1 = +0·1587 b_2 = —0·0577
	Error	28	86·83	231·20	2·50	Adjusted variance	120·76	1·16	1·82	1·48
			Covariance I×II	Covariance II×III	Covariance I×III					
D	Error	28	+99·82	+2·50	+8·02	Relative precision	1·9145	2·1551	1·3736	1·6892
	Percentage standard error		9·45	16·45	14·59	Percentage gain or loss of precision	+91·45	+115·51	+37·36	+68·92
			Chari 1929 I Mean sq.	Wheat 1929-30 II Mean sq.	Wheat 1930-31 III Mean sq.	Coefficient of regression (*b*)	—0·0273	+0·6657	+0·1486	b_1 = +0·1935 b_2 = +1·6444
	Error	28	647·60	3·50	81·61	Adjusted variance	3·13	83·02	69·80	63·71
			Covariance I×II	Covariance II×III	Covariance I×III					
E	Error	28	—17·70	+2·33	+96·22	Relative precision	1·1192	0·9830	1·1692	1·2809
	Percentage standard error		22·58	14·17	14·98	Percentage gain or loss of precision	+11·92	—1·70	+16·92	+28·09

TABLE III

Mean yield in mds. per acre and coefficient of variation of each block in different years (Montgomery, Square 17)

Division	Crop and year	Blocks												Remarks
		1		2		3		4		5		6		
		Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	Mean yield	Coeffi-cient of varia-tion	
A .	Wheat 1932-33 .	71·4	16·62	54·0	11·93	56·4	7·18	53·0	6·40	60·0	7·82	59·8	7·58	
	Wheat 1933-34 .	29·2	24·38	35·0	18·86	13·8	26·81	18·2	21·43	18·4	21·96	16·6	28·74	
	Chari 1934 . .	124·2	21·16	97·8	26·21	93·8	10·10	84·0	11·39	90·8	19·40	93·2	8·29	
B .	Wheat 1932-33 .	57·2	15·32	50·8	·28	46·6	3·91	36·8	13·37	31·4	13·82	36·2	8·15	6 blocks of 5 plots each
	Wheat 1933-34 .	19·4	44·12	16·2	44·20	11·8	18·39	10·2	10·79	9·2	32·06	8·4	13·57	
	Chari 1934 . .	58·6	14·86	18·6	52·10	27·4	69·67	66·0	22·29	70·8	19·70	93·2	16·73	
C .	Wheat 1932-33 .	90·2	10·24	78·8	5·77	67·2	7·47	55·0	12·93	54·6	8·26	60·6	4·75	
	Wheat 1933-34 .	13·6	24·19	10·8	21·11	7·2	20·56	6·6	23·03	8·2	41·70	7·4	38·92	
	Chari 1934 . .	81·2	10·79	82·4	10·97	43·0	41·57	15·8	57·90	41·6	48·72	106·0	12·15	
D .	Wheat 1932-33 .	44·8	22·39	45·2	14·72	33·8	8·97	32·0	17·69	27·6	15·91	33·6	6·84	
	Wheat 1933-34 .	10·8	40·56	8·6	22·10	10·0	25·50	11·8	33·05	12·6	7·06	7·2	6·25	
	Chari 1934 . .	84·2	6·79	68·8	11·79	72·6	10·19	62·8	28·43	60·6	26·26	123·2	28·60	

TABLE IV

Analyses of variance and covariance for different crops (Montgomery, Square 17)

Division	Due to	Analyses of original yields					Adjustment by covariance			
		Degrees of freedom	Wheat 1932-33 I	Wheat 1933-34 II	*Chari* 1934 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I & II
	Error	24	Mean sq. 42·05	Mean sq. 27·00	Mean sq. 316·60	Coefficient of regression (*b*) .	—0·4611	—0·7341	—0·0357	b_1 = —0·5594 b_2 = —1·1358
A . .	Error	24	Covariaance I×II —19·39	Covariaance II×III —19·82	Covariaance I×III —1·50	Adjusted variance . .	18·85	315·18	330·31	319·94
						Relative precision .	1·4324	1·0045	0·9585	0·9896
	Percentage standard error		15·36	33·34	25·60	Percentage gain or loss of precision	+43·24	+0·45	—4·15	—1·04
	Error	24	Mean sq. 24·23	Mean sq. 23·38	Mean sq. 156·40	Coefficient of regression (*b*) .	+0·3207	+0·3614	+0·2200	b_1 = +0·1165 b_2 = +0·3227
B . .	Error	24	Covariaance I×II +7·77	Covariance II×III +8·45	Covariance I×III +5·33	Adjusted variance . .	21·80	160·02	161·98	166·98
						Relative precision . .	1·0725	0·9774	0·9656	0·9366
	Percentage standard error		15·65	52·67	30·27	Percentage gain or loss of precision	+7·25	—2·26	—3·44	—6·34
	Error	24	Mean sq. 35·03	Mean sq. 6·75	Mean sq. 190·01	Coefficient of regression (*b*) .	+0·1644	+0·5378	+0·3546	b_1 = +0·3096 b_2 = +0·2736
C . .	Error	24	Covariance I×II +5·76	Covariance II×III +3·63	Covariance I×III +12·42	Adjusted variance . .	6·05	196·24	194·68	202·02
						Relative precision . .	1·1157	0·9683	0·9760	0·9406
	Percentage standard error		12·23	40·63	31·24	Percentage gain or loss of precision	+11·57	—3·17	—2·40	—5·94
	Error	24	Mean sq. 35·11	Mean sq. 7·63	Mean sq. 327·93	Coefficient of regression (*b*) .	+0·1242	—0·6160	—0·3159	b_1 = +0·4223 b_2 = —0·8573
D . .	Error	24	Covariance I×II +4·36	Covariance II×III —4·70	Covariance I×III +11·09	Adjusted variance . .	7·40	339·16	338·54	348·27
						Relative precision . .	1·0311	0·9821	0·9687	0·9416
	Percentage standard error		22·98	37·80	32·23	Percentage gain or loss of precision	+3·11	—1·79	—3·13	—5·84

TABLE V

Mean yield in mds. per acre and cœfficient of variation of each block in different years

(Montgomery, Square 28)

Division	Crop and year	Blocks												Remarks
		1		2		3		4		5		6		
		Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
A	Wheat 1931-32	108·6	4·78	107·6	4·85	113·6	4·68	117·6	4·88	102·3	4·85	105·4	2·18	
	Chari 1932	108·4	8·47	93·9	11·64	108·0	18·42	129·4	9·23	101·7	12·56	102·1	9·38	
B	Wheat 1931-32	78·7	10·75	99·1	6·12	103·9	4·60	105·4	6·00	98·0	5·31	106·1	6·04	
	Chari 1932	100·3	7·76	93·0	16·11	100·4	11·70	117·4	13·33	110·1	13·83	121·3	10·88	
C	Wheat 1931-32	99·7	5·32	85·1	5·73	78·0	11·44	89·9	9·30	100·6	6·54	115·0	8·88	
	Chari 1932	110·7	14·84	106·6	9·50	90·7	8·19	106·4	13·84	110·9	3·70	132·4	9·44	
D	Wheat 1931-32	104·0	6·26	97·3	5·56	93·4	7·76	102·4	4·75	111·4	6·85	112·6	3·80	
	Chari 1932	100·3	13·86	99·1	5·42	88·4	14·75	90·7	10·37	113·6	4·80	127·0	7·64	

TABLE VI

Analyses of variance and covariance for different crops

(Montgomery, Square 28)

Division	Due to	Analysis of original yields					Adjustment by covariance			
		Degrees of freedom	Wheat 1931-32 I Mean square	*Chari* 1932 II Mean square	Covariance I × II		Coefficient of regression (*b*)	Adjusted variance	Relative precision	Percentage gain or loss of precision
A	Error	36	24·22	166·24	+2·67	II corrected for I	+0·1103	170·69	0·9739	—2·61
	Percentage standard error		4·41	12·01						
B	Error	36	39·88	176·42	+41·58	Do.	+1·0430	136·87	1·2890	+28·90
	Percentage standard error		6·31	12·40						
C	Error	36	58·20	136·25	+32·54	Do.	+0·5591	121·43	1·1220	+12·20
	Percentage standard error		8·06	10·65						
D	Error	36	37·40	146·98	+36·80	Do.	+0·9844	113·94	1·2900	+29·00
	Percentage standard error		5·95	11·75						

TABLE VII

Mean yields in maunds per acre and coefficient of variation of each block in different years

(Karor, Muzaffargarh district)

Crop and year	Blocks												Remarks
	1		2		3		4		5		6		
	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
Chari 1930	63·70	12·27	113·80	7·94	123·80	12·83	140·20	14·73	112·30	7·74	71·50	27·57	Six blocks of six plots each
Wheat 1930-31	20·83	20·96	22·42	12·88	33·00	30·01	22·75	30·20	20·33	9·41	18·33	16·51	
Wheat 1931-32 . .	66·00	12·57	66·00	10·14	94·00	10·59	67·33	13·50	58·67	16·93	50·67	14·05	

TABLE VIII

Analyses of variance and covariance for different crops

(Karor)

Due to	Analysis of original yields					Adjustment by covariance			
	Degrees of freedom	*Chari* 1930 I	Wheat 1930-31 II	Wheat 1931-32 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I×II
		Mean sq.	Mean sq.	Mean sq.	Coefficient of regression (b) .	+0·0020	+0·4746	+0·0643	$b_1 = +0·0633$ $b_2 = +0·4733$
Error	30	336·69	30·93	74·00	Adjusted variance . .	31·98	69·31	75·08	70·37
		Covariance I×II	Covariance II×III	Covariance I×III					
Error	30	+0·66	+14·68	+21·64	Relative precision . .	0·9671	1·0677	0·9856	1·0516
Percentage standard error .		17·62	16·85	12·82	Percentage gain or loss of precision	—3·26	+6·77	—1·44	+5·16

TABLE IX

Mean yield in mds. per acre and coefficient of variation for each block in different years

(Lyallpur)

Crop and year	Blocks												Remarks
	1		2		3		4		5		6		
	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
Chari 1929	162·3	6·89	192·9	13·77	160·1	10·69	221·9	14·01	171·1	12·06	200·4	13·58	6 blocks of 7 plots each.
Wheat 1929-30	28·3	40·35	22·8	22·81	39·6	15·15	42·0	13·57	50·6	12·39	46·0	15·94	
Chari 1930	240·1	37·08	198·1	21·84	242·9	9·32	258 3	9·91	255·4	9·01	202·1	8·86	

TABLE X

Analyses of variance and covariance for different crops

(Lyallpur)

Due to	Analysis of original yields					Adjustment by covariance			
	Degrees of freedom	*Chari* 1929 I	Gram 1929-30 II	*Chari* 1930 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I&II
		Mean sq.	Mean sq.	Mean sq.					
Error	36	542·80	53·31	1970·95	Coefficient of regression (b)	+0·0945	+4·4865	+0·1907	b_1 = —0·1503 b_2 = —0·0104
		Covariance I×II	Covariance II×III	Covariance I×III	Adjusted variance	49·84	923·22	2006·96	916·04
Error	36	+51·31	+239·21	+103·52	Relative precision	1·0696	2·1349	0·9821	2·1516
Percentage standard error		12·61	17·06	13·34	Percentage gain or loss of precision	+6·96	+113·49	—1·79	+115·16

TABLE XI

Mean yield in mds. per acre and coefficient of variation of each block in different years

(Gurdaspur)

Crop and year	Blocks												Remarks
	1		2		3		4		5		6		
	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
Chari **1929**	110·4	7·12	128·5	9·60	183·7	9·10	175·9	5·13	157·7	7·98	151·6	10·60	6 blocks of 11 plots each.
Gram 1929-30	37·6	25·37	58·7	16·80	46·5	23·78	44·5	41·66	31·1	29·07	11·8	23·65	
Chari 1930	74·4	28·17	58·3	12·52	147·4	8·58	133·4	8·13	112·3	9·59	85·3	18·14	

TABLE XII

Analyses of variance and covariance for different crops

(Gurdaspur)

Due to	Analysis of original yields					Adjustment by covariance			
	Degrees of freedom	*Chari* 1929 I	Gram 1929-30 II	*Chari* 1930 III		II corrected for I	III corrected for II	III corrected for I	III corrected for I & II
		Mean sq.	Mean sq.	Mean sq.					
Error	60	165·23	123·98	187·61	Coefficient of regression (b) .	+0·0645	—0·1775	—0·1496	b_1=—0·1503 b_2=+0·0104
		Covariance I×II	Covariance II×III	Covariance I×III	Adjusted variance . .	125·37	190·78	187·02	190·23
Error	60	+10·65	—0·22	—24·71	Relative precision . .	0·9889	0·9834	1·0020	0·9862
Percentage standard error		8·49	28·98	13·46	Percentage gain or loss of precision.	—1·11	—1·66	+0·20	—1·38

TABLE XIII

Mean yield in mds. per acre and coefficient of variation of each block in different years

(Hansi)

Division	Crop and year	Blocks 1		2		3		4		5		6		7		8		9		Remarks
		Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	Mean yield	Coefficient of variation	
A	*Chari* 1930	249·3	5·29	255·3	16·50	233·5	8·59	176·5	15·08	20·2	10·43	187·3	6·92							6 blocks of 6 plots each
	Chari 1931	119·3	14·07	113·8	15·06	96·3	17·65	82·2	9·28	87·0	13·60	79·2	12·86							
B	*Chari* 1930	190·9	17·98	150·9	12·98	130·1	16·00	159·4	8·61	157·3	8·48	160·2	7·53	184·7	10·88	183·7	6·17	186·6	4·11	
	Chari 1931	87·3	12·52	82·8	12·79	83·7	13·74	95·8	18·78	108·7	6·59	80·6	8·19	88·9	13·37	90·3	10·01	96·6	11·68	9 blocks of 0 plots each

TABLE XIV

Analyses of variance and covariance for different crops

(Hansi)

Division	Due to	Analysis of original yields					Adjustment by covariance			
		Degrees of freedom	*Chari* 1930 I Mean square	*Chari* 1931 II Mean square	Covariance I×II		Coefficient of regression (*b*)	Adjusted variance	Relative precision	Percentage gain or loss of precision
A	Error Percentage standard error	30	618·99 12·87	155·57 12·95	+23·16 ...	II corrected for I	+0·0374	160·00	0·9724	—2·76
B	Error Percentage standard error	72	344·30 11·11	125·85 11·27	+55·23 ...	Do.	+0·1604	118·64	1·4930	+49·30

PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

III. THE ROOT-SYSTEM

BY

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(With Plates XV and XVI)

Introduction

THE plant itself is after all the best indicator of the biotic condition in the soil, and plant methods are slowly replacing chemical methods in these biotic investigations. Among the different organs of the plant, roots are the means by which the plant is brought ' into gear ' with the soil, and any attempt at improvement in the soil conditions for securing the highest possible yields either by cultivation, manuring or irrigation should aim at increasing the activity of roots, which are the principal agents for supplying water and nutrients for the growth of the crop. The study of the development of the root-system should thus form an important part in any biotic investigation, and more so in the case of sugarcane in the Deccan Canal tract, as its cost of cultivation is very high. We have, therefore, given it its due share of importance in our various investigations and these results are discussed in the following pages.

Historical

In the study of the root-system of sugarcane, Venkatraman [1922], Venkatraman and Thomas [1924, 1929], and Thomas [1927] may be said to be the pioneers, who by rather ingenious methods differentiated between the functions of the two types of roots, viz. (1) sett roots developing from the root eyes of the planted sett, and (2) shoot roots growing from the shoot. According to them, both types of roots are essential for normal development of cane. Sett roots are temporary, being needed for germination and growth of the bud ; but once shoot roots are established, these take over the function of supplying cane with water and mineral salts. These workers are also responsible for much of the earlier work on the development of the root-system from early stages to maturity both in pots as well as directly in the field in the normally planted crop. In the latter case, a pit is either dug vertically down the edge of the plant and roots in a specified thickness of soil extending from the stool to the right and left are carefully dissected out, or a pit is dug on one side of the

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plant, thin iron rods are inserted through the breadth of the interposed soil, and roots are then freed from the soil. In both the cases, according to them, the system can be conveniently studied and photographed.

During recent years much research has been carried out on quantitative basis on the development of roots in Hawaii [Lee and coworker, 1926, 1927, 1928, Weller, 1928, 1930 ; Alexander, 1928 ; Wolters, 1929], Cuba [Jensen, 1931], Java [Kulescha, 1931], Trinidad [Hardy, 1933], Mauritius [Evans, 1934, 1935, 1937, 1939] and Barbados [Stevenson, 1937]. Methods of root dissection as followed by these various workers can be differentiated as follows :—

(1) The 'box method' with horizontal wire netting placed between the boxes and the soil filled in those layer by layer as developed by Venkatraman and Thomas [1924].

(2) The 'direct examination method' of Weaver [1926] which consists in digging deep trenches at such a distance away from the stools as to leave the roots undisturbed in the block of soil encompassed by the trenches. Roots are then carefully freed from the soil either by dissection or washing with water starting with the upper layer, and from the distribution of the roots, plans of the root-system are drawn to scale.

(3) The 'block method' of Rogers which consists in marking a square area of ground round the stool sufficiently large to enclose all the roots by first obtaining an indication of the root-system by preliminary examination of the stool if necessary. The square is divided into four quarters and each of these is subdivided into areas of one foot square. Standing from outside the square, each square foot is examined in detail to a depth of six inches and the position of the roots is marked accurately to the scale on graph paper. Similar procedure is followed for the next six inches and so on until the whole root-system is dissected out.

(4) The 'trench method' as developed by Evans [1935]. This involves working a trench to a depth of one foot at a suitable distance from stools to be examined. The side of the trench is worked towards the stool for a few inches with hand picks and all the roots entering into the trench are marked to scale on graph paper. The trench is then widened to two feet and deepened to two feet and the roots similarly exposed. The trench is thus widened by successive foot widths with an increase in depth of one foot for each such increase in width.

(5) The 'soil core method' of Hardy [1933] which consists of taking cores of soil three inches in diameter, two to three feet deep and 4, 11 and 18 inches radially from the centre of the stool ; and the quantity of roots are estimated from these cores.

The results of studies thus conducted by various workers can be summarized as follows :—

(1) Soil texture greatly affects root growth, the development of roots being better in well-drained soils than in badly drained ones [Lee, 1926 ; Alexander, 1928 ; Venkatraman and Thomas, 1929 ; Jensen, 1931]. Kulescha [1931], who studied the behaviour of POJ 2878 in six soil types by the direct examination method, has concluded that the character of the root-system is markedly affected by the type of soil as regards distribution, number, length of roots and the maximum depth to which they descend. Hardy [1933], who

did his studies with the soil core method, however, does not find the effect of the soil texture to be very marked.

(2) The quantity of roots is generally increased by the application of fertilizers. Wolters [1929] has, however, found a marked correlation between root growth and crop growth irrespective of the fertilizer treatment or irrigation under the same soil conditions. This would appear to show that fertilizers do not exert a specific effect on the root-system alone, this beneficial effect being reflected on the stool as well. Venkatraman and Thomas [1929] also find a positive correlation of the above-ground portion with the growth vigour of the shoot roots. On the other hand, Evans [1938] does not find any close relationship between the development of the roots and the above-ground parts. Hardy [1933] also maintains that there is no simple relationship between root weights and crop weights.

(3) Soil moisture has an important effect on the root-system, adequate soil moisture favouring surface rooting and low soil moisture deep rooting [Stevenson, 1937]. Venkatraman and Thomas [1929] find the effect of irrigation with saline water to be adverse to root development.

(4) There is a marked variation in the root-system of the different varieties, and Venkatraman [1929] has emphasized the necessity of working out the typical root-system of each variety as it would be a good guide in manurial and cultural operations. Evans [1935] has differentiated between three types of roots: (*a*) superficial roots, (*b*) buttress roots, and (*c*) the rope system, the two latter going deep into the soil. In noble canes, superficial roots are well developed, while canes containing wild blood develop more of the deeper roots. He has further found the shoot/root ratio to be different for different varieties. Some varieties make a good aerial growth with a mediocre root-system, while others have an extensive root-system with similar or even less vigorous top growth.

METHOD USED IN THE PRESENT INVESTIGATION

During the course of our investigations it was observed that application of such artificial methods as planting in: (1) pots, (2) rings, or (3) in isolated positions in the field with a free space all round the stool induced the development of a root-system differing greatly from that of the normally planted crop. In pots, although the soil was compacted layer by layer as occurring in the field, the root-system of POJ 2878 permeated in all the three feet depth of soil, while under field conditions it was restricted to the first two feet depth of the same soil. So also in the case when buds were planted in isolated position, the spread of the root-system was almost uniform all round the stool. Under normal planting, this spread is mainly on two sides of the stool, as there is very little space between the two germinated buds in the same row to permit root development in between them. We therefore eschewed all these artificial methods for the quantitative studies. Among the methods considered to be suitable for the examination of the root-system *in situ* Hardy's method was found to be inadequate for giving a true picture of the system, while other methods, such as the 'block method', the 'direct examination method' or the 'trench method', were found to be too laborious and time-consuming. Besides, the adoption of these methods tends to a great wastage of the plant material owing to the necessity of digging trenches either all round the stool under examination or on its opposite sides. These methods were thus considered impracticable in application during the development of the crop in the experimental layout of varieties, manuring, irrigation, etc. In the comparative studies of the various methods in vogue, digging of a pit vertically down the edge of the stool and exposing the root-system by washing the soil in a specified zone was found to be the best. It leads to the least wastage of the plant material as it practically does not disturb other plants. It is very rapid, two labourers being capable of exposing roots of eight to ten stools per day. It is also quite accurate for quantitative work if certain precautions as enumerated below are taken.

In the Deccan Canal tract, cane setts are planted in furrows four feet apart with 10,000 three-budded setts per acre. Taking the germination to be about 70 to 80 per cent, germinated buds will have only a space of about six inches in between them in the same row for the development of roots. Thus a thickness of soil, equal to six inches, will contain practically all the roots of the stool under examination on its both the right and left sides in the intervening space between the adjoining furrows. A normally developed cane stool, away from the water channel and protected from wind, is selected almost at the end of a row in the treatment under study. One or two stools at the end of the row, which get the advantage of extra space, are removed and a trench is dug about two feet wide and two to three feet deep right across the row extending about 2½ ft. on either side of the selected stool. The soil is then gently washed off by means of a fine spray pump, taking care not to dislodge the roots from their natural position while tracing them (Plate XV, fig. 1). If the soil is too compact, it can be gently loosened with a sharp pointed needle. No difficulty in washing off the soil is experienced, if the soil is kept at its moisture equivalent for about 24 hours before starting root excavations. If the soil is too dry, small clods are formed, which, while being dislodged by the spray, tear away the fine roots. In this soil, the second or the third day after irrigation is found to be the most suitable period from the point of soil moisture. Washing is very easy and no roots—not even the finest ones—are lost in the washing.

The root-system is now ready for taking observations. Counts of the number of roots of different diameters can be then taken and sketches drawn to scale. The root-system can be also conveniently photographed. For quantitative determinations, roots are cut in squares of 6 or 12 in. from the centre of the stool marked out by means of pins, which are passed through an iron frame divided into these squares (Plate XV, fig. 1). These roots are then washed free of soil with water by placing them on a fine meshed sieve, dried in the oven and the dry weights are recorded (Table I).

Canes from which roots are cut are also weighed and samples are kept for the moisture content in order to determine the shoot/root ratio.

GENERAL CHARACTERISTICS OF THE ROOT-SYSTEM

Immediately after planting, sett roots begin to develop within a week to a fortnight, depending upon the condition of the sett and the atmospheric temperatures. According to Rege and Wagle [1939], minimum temperatures below 50°F. are inhibitive to the activities of the sett, which remains generally dormant under such conditions. In a three-budded sett, which is commonly used as a planting material in this tract, a gradient in the development of roots from the bottom to the top node is observed, the largest quantity of roots being formed in the case of the bottom node. On the other hand, buds at the middle and top nodes, which sprout earlier, produce more vigorous shoots than the bottom one (Table II). Similarly, in the whole cane, basal nodes produce more profuse roots than apical ones. This is explained by Loeb [1919] by the transfer of inhibitors produced by the topmost buds towards the base of the stem, leaving the buds at the apex clear of these ; and their downward current has a stimulating action on the development of roots at the nodes below.

TABLE I

Distribution of roots of a cane stool

(Oven-dry weights

POJ 2878—225 lb. N
Stool weight — 461·6 gm.

$$\frac{\text{Stool weight}}{\text{Root weight}} = 16\cdot 9$$

Stool

gm.	1·66	6·06	8·51	1·74	gm.
		65.9 per cent			
,,	1·51	2·37	3·80	1·63	,,
		34·1 per cent			

(Each square is 1 ft. × 1 ft.)
Total weight —27·28 gm.

TABLE II

Behaviour of three-budded setts during germination

(Average of 6 rows each with 30 three-budded setts)
Variety—POJ 2878

Date of planting	Position of the bud	Oven-dry weight per germinated shoot in gm. at 8 weeks from planting	
		Shoot	Roots
10 Feb. 1937 . .	Bottom	4·78	0·65
	Middle	7·48	0·45
	Top	6·61	0·37
26 Feb. 1937 . .	Bottom	5·43	0·57
	Middle	8·27	0·45
	Top	7·37	0·43

Shoot roots are formed soon after germination and these are generally whiter and thicker than sett roots. They can be, therefore, easily distinguished from the others, which are thinner and more superficial. With the progress in the development of the shoot roots, these sett roots cease to function and soon die. A general idea about the periodical increase in the number of roots, their thickness, lateral spread and depth of penetration from germination to harvest time is given in Table III.

TABLE III

Periodical development of the root-system

(Average of four stools)

Variety—POJ 2878

Period	No. of roots				Total	Depth of penetration in inches	Lateral spread in inches
	Thin (0·5 — 1·0 mm. in dia.)	Medium (1·1 — 1·5 mm. in dia.)	Thick (1·6 — 2·5 mm. in dia.)	Very thick (2·6 mm. and above in dia.)			
2 months	25	...	10	...	35	9·5	9·0
5½ months (i.e. just before earthing)	20	20	10	...	50	18·0	24·0
7½ months	61	75	19	...	155	24·0	24·0
Harvest time (11 months) .	98	76	65	24	263	28·0	24·0

Before the operation of earthing, roots penetrate through the whole mass of soil in the ridge which contains much of the assimilable nitrogen. The depth of penetration during this period is comparatively less and does not exceed 1½ ft. During the course of earthing, most of the roots in the ridge are pruned and this pruning is considered to be necessary for good growth. This belief is, however, found to be quite untenable by Rege and Wagle [1939] who have shown that for securing good growth, pruning of roots is not an essential prerequisite. Earthing covers two to three nodes depending upon the height of earthing and all these nodes produce roots, thus increasing their number to a great extent. This is also the time when the plant starts its grand period of growth and both the root and shoot activities are at their highest. There is profuse branching of roots at this period with an increase also in their depth penetration. This has, however, never exceeded 36 in. in this soil, inclusive of the earthed-up portion, in spite of diverse treatments.

From the standpoint of the functional behaviour of roots, there does not seem to be any clear differentiation as has been shown by Evans [1935]. No doubt, as the shoot develops and increases in height and weight, the older roots get thicker and thus can afford the plant some support for anchorage. But this cannot be considered to be the only function of these roots as although they do resemble the dead ones, some of them are found to possess living roots in the proximity of their ends, which serve as absorbing agents of nutrients as well.

INFLUENCE OF ENVIRONMENTAL FACTORS

(a) *Soil*

Soils of the Deccan Canal tract belong to the broad group of ***regur*** or black cotton soil, which is further classified by Basu and Sirur [1938] into soil types possessing distinct chemical and physical properties. Two of these types are available at this station and the quantitative data of the root behaviour in these types are given in Table IV. The type F has a soil depth of about 18 in. with soft *murrum* substratum, while in the case of type B, the depth of soil varies from 3 to 7 ft. In the latter case, the root studies are, therefore, carried out at two locations, one having a shallower phase (4 ft.) and the other a deeper phase (7 ft.). For convenience, they will be termed B medium and B deep respectively.

It is evident from the above data that the effect of soil type is pronounced both in the root and stool weights, the more so in the case of Pundia than POJ 2878. There is a progressive fall in the weights of roots with the increase in the depth of the soil, and even in the same soil type, the depth seems to be important in determining root behaviour. This effect is quite distinct at the early stages of crop growth, and although weights of shoots have not been taken at this period, inspection of the crop showed it to be poorer in the B deep as against B medium. In the F type, the performance of both roots and shoots has been the best from the start and this is reflected in the final stool weights, which are distinctly superior to those in the other type. General observations in the canal tract would appear to indicate that shallower types are better yielders than deeper ones. The root-system in these shallow types contains a larger number of thin roots which penetrate through the whole soil mass, and further the penetration of roots has been observed even in the *murrum* substratum to a depth of 6 to 9 in. Cultivation is not found to be so important in this as well as in the B medium as in the B deep, wherein after a period of five years of cane growing, a great improvement in the spread of roots was observed in the first two feet depth of soil. This was further confirmed by the quantitative data which showed an increase of 28 per cent in root weights over those in Table IV. No improvement was, however, observed in their depth penetration.

In order to properly evaluate the nature of the influence of these soil types on root growth, it must be clearly understood that sugarcane in this tract is an entirely irrigated crop, receiving waterings at eight to ten days intervals and is generally heavily manured with nitrogenous top dressings, both in the form of oil-cakes and sulphate of ammonia distributed three to four times during the development of the crop. Such limitations as the availability of moisture and nutrients, which are some of the important characteristics of soil types, are therefore masked to a great extent by these treatments. In fact, the good development of such a long-duration crop like sugarcane in shallow types as F can only be possible by the proper maintenance of these two factors. Not only is the water-holding capacity of this soil slightly lower than that of the other type but, owing to the limited soil mass in this type, it contains comparatively less water and nutrients. Studies in capillary movement have also proved it to be practically absent in the *murrum* substratum. The availability of water as well as nutrients for the life processes of

TABLE IV

Influence of soil on the root-system

(Average of four stools)

Soil type	Pundia						POJ 2878					
	Oven-dry wt. of		**Per cent distribution of roots**				**Oven-dry wt of**		Per cent distribution of roots			
	Canes in stool (gm.)	Roots (gm.)	Stool wt.† / Root wt.	0-12″	12-24″	24-36″	Canes in stool (gm.)	Roots (gm.)	Stool wt.† / Root wt.	0-12″	12-24″	24-36″
June 1934												
F type	..	15·30	..	75·6	24·4*	..	..	18·75	..	53·8	46·2	..
B medium	..	10·95	..	66·0	34·0	..	..	15·45	..	61·4	38·6	..
B deep	..	6·60	..	65·3	34·7	..	..	12·90	..	57·0	44·0	..
December 1934												
F type	749·0	24·00	31·2	49·5	50·5	..	628·3	35·70	17·6	50·1	49·9	..
B medium	490·5	15·75	31·1	45·2	38·3	16·5	584·8	39·30	14·9	40·7	30·1	29·2
B deep	413·0	15·90	26·0	50·4	35·2	14·4	583·8	21·45	27·2	38·6	35·2	26·2

*The penetration of the roots did not exceed 18 in. in this soil

†Only weight of canes is taken

the crop would, therefore, be ordinarily much less in this type than in the others, and it is only by the system of irrigation and manuring that they are maintained at the proper level. As the root studies in all these soils have been carried out in experiments receiving exactly similar treatments of irrigation and manuring, poorer development of both roots and shoots in B medium and B deep can be attributed mainly to poorer soil aeration. The determination of oxygen at different depths by aloin test has shown it to be about 20 per cent less up to 32 in. as compared to surface 12 in. and 60 per cent less below this depth. The non-occurrence of roots below three feet in the deep soil would be thus explicable. This disinclination of roots to penetrate deeper layers has been observed even after adverse treatments, such as withholding irrigation or manuring. Even subsoiling to a depth of four feet has not been effective. The deficiency of oxygen is, therefore, a potent factor in limiting the distribution of the root-system in this soil. This deficiency appears to be accentuated in the *chopan* soil (alkali soil) in which the root-system is still restricted under quite similar treatments and is present only in the first two feet depth of the soil (Table V).

TABLE V

Root study in chopan *soil*

Variety—Co 413..150 lb. N per acre
(October 1937)
Average of five stools

Soil	Oven-dry wt. of		Per cent distribution of roots			Stool wt. / Root wt.
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Chopan . .	832	23·6	65·5	34·5	..	35·2
B deep .	780	28·7	47·0	31·1	21·9	27·2

This soil falls genetically under the same B type, but is a degraded one owing to the accumulation of sodium in the colloid complex, which has adversely affected the drainage and has thus increased the deficiency of oxygen in the lower layers.

(*b*) *Soil moisture*

As sugarcane is a totally irrigated crop under Deccan conditions, receiving water at intervals of ten days, the question of the deficiency of soil moisture does not generally arise. On the other hand, there has been a tendency on the part of the cultivators to over-irrigate the crop. Some root studies were, therefore, carried out in an experiment with varying quantities of water and nitrogen and the results are given in Table VI.

TABLE VI

Effect of varying quantities of water and nitrogen on the root-system, December 1937

(Average of 4 stools)

Treatments	Oven-dry wt of		Per cent distribution of roots			$\frac{\text{Stool wt.}}{\text{Root wt.}}$
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
POJ 2878						
95″+225 N .	696·3	33·4	46·4	38·4	15·2	20·9
130″+225 N .	680·4	36·7	51·8	35·0	13·2	18·5
95″+300 N .	761·8	37·4	45·3	40·2	14·5	20·4
130″+300 N .	905·9	39·9	52·8	39·1	8·1	22·8
Pundia						
95″+225 N .	796·0	24·2	66·7	31·1	2·2	32·9
130″+225 N .	666·2	23·3	71·1	23·0	5·9	28·6
95″+300 N .	835·1	23·6	63·6	24·2	2·2	35·4
130″+300 N .	696·0	20·3	72·6	24·2	3·2	34·3

In general, it may be stated that higher watering tends to produce a superficial root-system as could be seen from the higher percentage of roots in the first foot depth of soil in this watering. Further differentiation in the influence of watering is found to be dependent on the varietal characteristics. In the case of POJ 2878, there has been an increase in the total quantity of roots in higher watering with the same manurial dose. The availability of nutrients can be said to be responsible for this increase, as the higher watering is apt to leach down the nutrients to a greater extent than the lower one. On the other hand, Pundia shows a definite tendency towards a fall in the root weights with higher watering. Studies in soil moisture before every irrigation have shown a higher level of moisture in the plots with Pundia than in those with POJ 2878. The irrigational dose in the case of 130 acre-inches may, therefore, be excessive in the case of the former, creating partially waterlogged conditions. Pundia is found to be more susceptible to the deficiency of soil aeration than the other variety. It has been in fact a general experience that Pundia makes very poor growth in heavier types of soil with impeded drainage or under waterlogged conditions, while POJ 2878 does not suffer to the same extent. Weights of stools given in Table VI also clearly indicate that, while in the case of POJ 2878 there has been practically no fall in weight in higher watering with the same manurial dose—and in fact in the case of 300 lb. of nitrogen there has been a definite gain—the reverse is the case with Pundia, both the manurial treatments showing a definite fall in weight in this watering. Final yield data have also shown similar trend in all these treatments. It is thus evident that in the case of higher watering (130 in.) partially waterlogged conditions are created which have adversely affected the growth of the root-system in the case of Pundia, the result being reflected in the weights of stools also.

Although in the general system of irrigation in vogue, there is little possibility of the crop suffering from shortage of water, some studies on its influence on the root-system have been also carried out both by stopping irrigation till plant showed permanent wilting and secondly by delaying waterings throughout the life of the plant such as 20 days interval as against the usual ten days between two turns. The stoppage of water till permanent wilting was adopted in April in all the three soils for two varieties—Pundia and POJ 2878—when the crop was about three months old, and it took about 24-40 days to attain this stage, depending upon the variety, soil type and depth, the longest period being required in B deep. Immediately on the attainment of this stage, the crop was irrigated with a very slow flow of water twice at an interval of five days and roots were then exposed in this as well as in the normal treatment, which was receiving watering after every ten days. A distinct variation in the root-system in both the treatments was observed, the stoppage of water leading to more lateral spread of roots, which is specially prominent in the case of POJ 2878. This is illustrated in Plate XV, figs. 2 and 3 for one soil only as similar behaviour has been observed in the other soils also. It is quite interesting to note that in spite of such severe treatment there has been very little penetration of roots in the lower depths. The inspection of the root-system showed that at the time of the attainment of permanent wilting by the shoot, all the roots had been dead, and it was only as the result of watering that thick, white roots were produced near the base of the stem which immediately gave an impetus to the growth of the crop, maintaining it at a higher level than the normal treatment. Consequently the plants were able to make up to a great extent for the loss in growth which was caused by the stoppage of water. The yield of millable canes at harvest would, however, depend upon the rate of damage by borers, which is higher during the course of the stoppage of water than in the normal treatment. In the case of POJ 2878, no adverse effect on final yields was observed due to this treatment. These varietal characteristics with the yield data will be dealt with in a separate paper and need not be discussed here.

The other experiment with delayed waterings was conducted in the B deep only and the results of root studies are given in Table VII.

TABLE VII

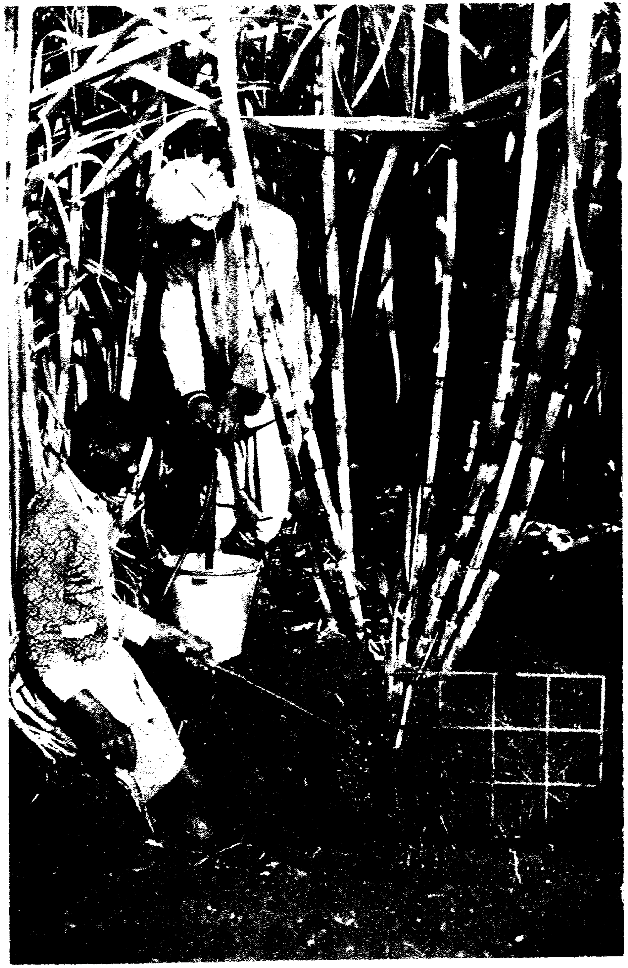
Effect of delayed watering on root development, December 1938

POJ 2878

(Average of four stools)

Soil	Treatment	Oven-dry wt of		Per cent distribution of roots			Stool wt. / Root wt.
		Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Deep	10 days irrigation .	928·1	19·95	58·8	35·9	5·3	46·5
	20 days irrigation .	750·2	20·85	52·6	35·4	12·0	35·9

ROOT-SYSTEM OF WILTED AND CONTROL STOOLS
(SOIL TYPE 'B' DEEP, POJ 2878)



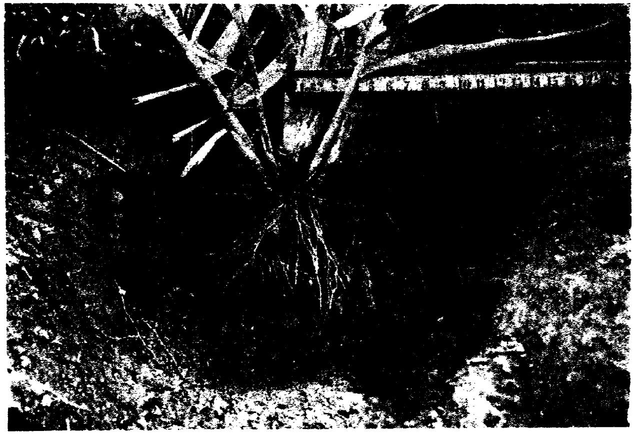
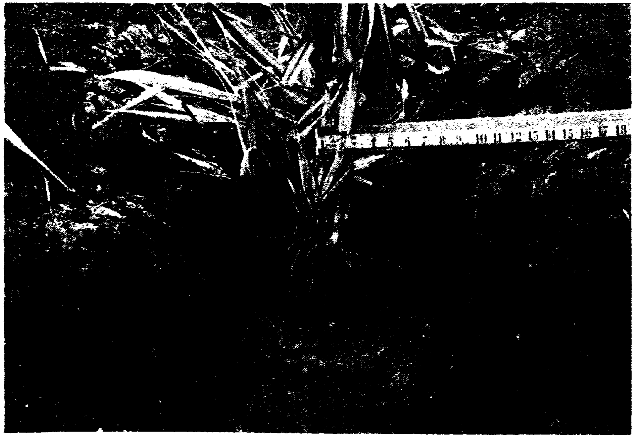


FIG. 2. Wilted



ROOT STUDIES OF SUGARCANE UNDER VARYING MANURIAL TREATMENTS

(POJ 2878)

Fig. 1. No N

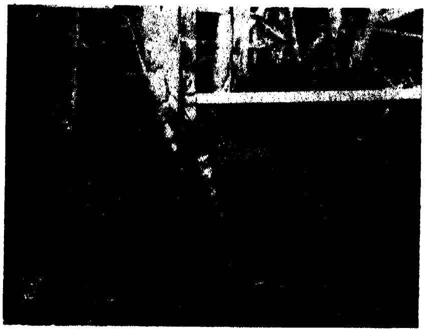


Fig. 2. 75 N

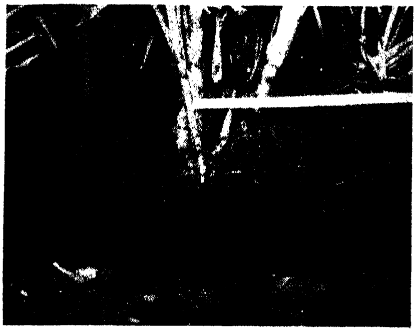


Fig. 3. 150 N

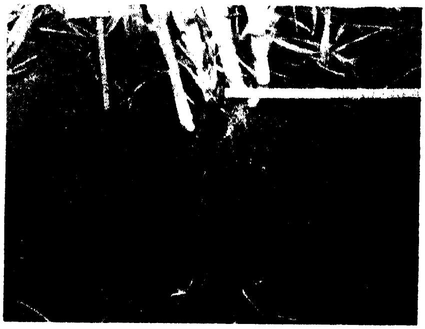


Fig. 4. 300 N

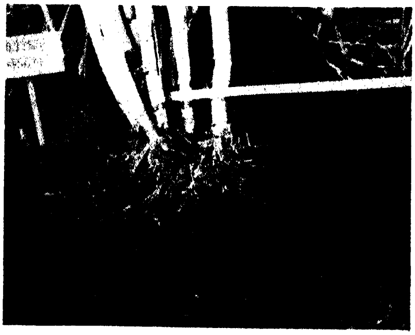


Fig. 5. 450 N

Fig. 6. 600 N

Although the total quantity of roots is practically similar in both the cases, it should be clear from their percentage distribution that in the case of 20 days irrigational turns, the root-system tends to be less superficial than in the normal treatment. The fall in the weight of stools, however, shows that in spite of this variation the crop has definitely suffered from the dearth of moisture as the soil nutrients were found to be on a higher level in this treatment than in the other. This can be ascribed to the failure of the root-system to penetrate deeper depths which were found on analysis to contain sufficiency of moisture throughout the period.

(c) *Nutrients*

In this tract, sugarcane is invariably manured, the most common manuring being the nitrogenous one consisting of sulphate of ammonia and oil-cakes. Soils are also found to be deficient in available phosphate, giving a good response to phsophatic manuring. During the course of the nutrition experiments with these elements, some studies in their influence on the root-system have also been carried out.

In the case of nitrogen, the treatments varied from no-nitrogen to 600 lb. of nitrogen, and the root-system is illustrated in Plate XVI for one of the two varieties under these treatments. The reduction in the root-system with increasing doses of nitrogen is quite visible. This has been further confirmed by the quantitative data for some of the treatments given in Table VIII which clearly indicate a progressive fall in the weights of roots with increasing doses of nitrogen.

TABLE VIII

Effect of varying doses of nitrogen on the root-system, November 1936

(Average of four stools)

Treatment	Oven-dry wt. of		Per cent distribution of roots			Stool wt. Root wt.
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
POJ 2878—						
150 lb. N	480·0	29·1	49·4	50·6	..	16·5
225 lb. N	495·7	27·0	61·1	38·9	..	18·4
300 lb. N	645·6	24·0	62·0	38·0	..	26·9
450 lb. N	674·2	23·3	54·7	45·3	..	28·9
Pundia—						
150 lb. N	553·5	20·3	73·4	26·6	..	27·3
225 lb. N	506·6	17·6	74·2	25·8	..	28·8
300 lb. N	448·6	17·1	64·1	35·9	..	26·2
450 lb. N	663·5	15·3	58·0	42·0	..	43·4

The weights per stool on the other hand show in general an increase with increasing doses of nitrogen and there is thus an inverse relationship between the growth of the stem and the roots, which is explained by Turner [1922] as due to the increased use of carbohydrates in the tops owing to their combination with nitrogen. This results, according to him, in a decrease in the supply of carbohydrates for the roots, which may bring about an absolute or relative reduction of root growth. The figures for the distribution of roots in both the varieties reveal a tendency towards their increase in the lower depth in the case of higher nitrogen. Figures are available only for 2 ft. depths, as the soil under experimentation had that much depth only. In all these treatments also the irrigational dose was common and was kept very moderate in order to avoid leaching of nutrients. The increase in the roots in the lower depths in the case of higher manuring does not seem to be due to the phenomenon of leaching down of nutrients beyond the root zone as, in that case, the effect would have been the reverse, the intensity of root penetration being more in the case of lower manuring than in the higher one. It thus appears that this distribution of roots in the case of higher nitrogenous doses is only meant to support the high weight of the cane with a view to preventing its lodging.

The effect of phosphate on the root development has been studied in another experiment with different forms of phosphatic manuring, a nitrogenous dose of 300 lb. per acre being common to all. These results are given in Table IX.

TABLE IX

Effect of phosphatic manuring on root development, November 1937

POJ 2878..300 lb. N per acre

(Average of four stools)

Treatments*	Oven-dry wt. of		Percentage distribution of roots			$\frac{\text{Stool wt.}}{\text{Root wt.}}$
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
No P_2O_5 . . .	779·8	28·7	51·5	29·5	19·0	27·2
Superphosphate 100+0 lb. P_2O_5 . . .	994·3	29·5	49·1	31·9	19·0	33·7
Superphosphate 50 +50 lb. P_2O_5 . . .	1,304·6	35·7	41·4	41·5	17·1	36·6
Bone-meal 50+50 lb. P_2O_5 . . .	1,249·3	31·7	38·5	42·1	19·4	39·4
Nicifos 50+50 lb. P_2O_5	1038·5	27·5	48·3	29·2	22·5	37·7

* The first dose of manure was applied at planting and the second at the time of earthing.

It will be seen that except in the case of Nicifos, there is a favourable effect of phosphatic manuring on the root development. This is quite striking in the treatments of superphosphate and bone-meal, in which their quantities are applied in two doses, while superphosphate applied in one dose at planting time has not been so very effective. Weights of stools are also much higher in these treatments, this increase being more pronounced than in the roots. It would be thus seen that unlike nitrogen, phsophatic manuring is found to increase the weights of both the roots as well as the tops, their relation being thus direct. Among different phosphatic manures, superphosphate appears to be the best both for the root and shoot growth, while Nicifos is not quite effective. The latter has completely failed to produce a favourable effect on the root-system, while there is some increase in the cane weights over the no-phosphatic treatment. Comparative studies of the data from Tables VIII and IX would thus explain the reason why certain workers have been able to find positive correlation between the crop growth and root growth and others have not. As regards the distribution of roots, there does seem to be a definite tendency towards their greater development in the lower depths with phosphatic manuring, it being quite evident in both superphosphate and bone-meal applied in two doses.

(*d*) *Wind*

The Deccan Canal tract is very windy, especially during the months of April-September, the average wind velocity during this period often exceeding ten miles per hour. Plants on the windward side are, therefore, always found to be stunted in growth. In order to study the effect of exposure to wind on the root-system, a few stools both on the windward and leeward side of the same plot were examined, and the results are given in Table X.

TABLE X

Effect of wind on root development, October 1937

Co 413, 300 lb. N+100 lb. P_2O_5

(Average of two stools)

Treatments	Oven-dry wt. of		Per centage distribution of roots			Stool wt. / Root wt.
	Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Exposd to wind .	409·1	37·2	58·3	34·0	7·7	11·0
Protected from wind .	486·8	25·4	37·4	31·6	31·5	19·2

Distinct variation in the root-system due to the exposure to wind is quite evident. Although the total quantity of roots is about 50 per cent higher than in the other case, the distribution o roots is quite superficial. This increased weight of roots is found to be due to their greater thickness and it seems that the great energy, spent by the exposed plant in producing thick root-system in order to support the plant against wind, is the main reason for the poor performance of the aerial portion. The shoot/root ratio is therefore abnormally low. The adverse effect of wind is generally observed on the first two to three rows and it is found that it can be entirely avoided by providing suitable wind-breaks.

ROOT DEVELOPMENT AND ITS RELATION TO DROUGHT RESISTANCE

Varietal trials in progress at this station have shown the superiority of some of the varieties over the indigenous one—Pundia. In order to find out whether their superior growth could be related in some way to the root development, root-systems of some of the promising varieties grown under the same treatment of irrigation and manuring were exposed and quantitatively studied. The depth of the soil was about four feet. The data are given in Table XI.

TABLE XI

Root development of varieties, October 1937

300 lb. N+100 lb. P_2O_5

(Average of four stools)

Variety	Fresh wt. of canes in stool (gm.)	Oven-dry wt. of		Percentage distribution of roots			Stool wt. / Root wt.
		Canes in stool (gm.)	Roots (gm.)	0-12″	12-24″	24-36″	
Pundia .	2579	392	13·4	64·9	25·8	9·3	29·3
Co 426 .	3988	738	25·6	54·3	33·6	12·1	28·8
H M 89 .	2636	488	22·8	52·7	36·7	10·6	21·4
Co 413 .	2677	667	30·3	51·8	27·2	20·9	22·0
Co 421 .	2499	507	33·3	51·9	32·5	15·6	23·2
POJ 2878 .	3653	669	26·7	53·9	29·2	16·9	25·1
Co 360 .	2420	411	21·0	52·3	31·1	16·7	19·6
E K 28 .	2545	471	26·7	59·9	29·0	11·1	17·7

It will be noticed that there is a considerable variation in the development of roots among the varieties with practically no relationship of any kind between the root and shoot growth. Pundia has an extremely poor root-system, which is, at the same time, much shallower than in the others and still it has produced a stool of fairly good weight equal to many others, e.g. HM 89, Co 413, Co 360 and EK 28, having a much better root development. It is only due to high moisture content of cane that its dry weight shows a fall as compared to the above-mentioned varieties. On the other hand, Co 421 has given the highest weight of roots, without any corresponding effect on the stool weight. The capacity for root development thus seems to be independent of the plant growth. Evans [1937] has also come to a similar conclusion and explains it as due to the fundamental difference in the shoot/root ratio in different varieties. From the inspection of the root-system of the varieties mentioned in Table XI, however, it seems that these varieties can be divided into two broad groups—one having thin and profusely branching root-system and the other possessing thick roots with comparatively less branching. The first group consists of varieties like Pundia, Co 360, EK 28, Co 426 and HM 89, while Co 421, POJ 2878 and Co 413 fall under the second group.

The data for distribution of roots clearly indicate that in all these promising varieties, more than 50 per cent of the roots are in the first foot depth of soil. Their maximum penetration has not also exceeded 3 ft., which is, as already explained, due to the deficiency of oxygen in the lower depths of this soil. There is practically very little variation among these improved varieties as regards the distribution of roots within different depths. This appears to be due to the controlled conditions of irrigation and manuring, and it has not been thus possible to draw any valid conclusions about the varietal characteristics from these studies alone. It was felt that this could be best achieved by the determination of their drought-resisting power. Besides anchorage, the main functions of roots would be the supply of water and nutriment to the various organs of plants, and the real criterion for judging the functional characteristics of the root-system should be its reaction to the deficiency of either of these. Irrigation was, therefore, stopped by about mid-April, when plants were about three months old and regular irrigations were begun only when each of the varieties showed a permanent wilting stage. The root-system was exposed after one more irrigation. An idea of the transpiring surface was also obtained by the product of the average length and breadth and the number of leaves. The data are given in Table XII.

TABLE XII

Relation of the root-system to the drought-resisting power of the varieties

Soil type—B medium

(Average of four stools)

Variety	Oven-dry wt of roots	Depth in.	Leaf area (sq. in.)	$\frac{\text{Leaf area}}{\text{Root wt}}$	No. of days required for wilting
Pundia	6·8	15·0	942·7	138·7	**32**
Co 426	8·7	19·0	999·7	114·9	**38**
HM 89	8·0	17·5	1164·2	145·5	**39**
EK 28	9·6	19·5	700·8	73·0	**39**
POJ 2878	9·8	27·0	937·0	95·7	**48**
Co 413	9·6	21·0	642·6	66·7	**48**
Co 360	12·0	26·0	656·8	54·7	**54**
Co 421	19·0	23·0	726·3	38·2	**54**

It will be evident that the influence of the root-system on the drought-resisting power of the varieties is circumscribed by their transpiring surface. In cases, however, where the transpiring surfaces are quite similar as in Pundia, Co 426 and POJ 2878 on the one hand, or Co 413, Co 421, EK 28 and Co 360 on the other, the period required for the attainment of permanent wilting is determined by the quantity of roots and their depth of penetration.

SUMMARY AND CONCLUSIONS

Trials of several qualitative and quantitative methods devised by various workers for the study of the root-system of sugarcane have been found either to represent unnatural conditions or to be mostly very elaborate and time-consuming, leading to a great wastage of plant material. The writers have developed a quick method under the irrigated conditions of the Deccan, which enables one to study root-system *in situ* both qualitatively and quantitatively and the same has been described in detail. It has been further applied to the study of the effect of different environmental factors on the development of roots and the shoot/root ratios and the results are briefly summarized below :—

(1) Studies in the general development of the root-system have shown a gradient in the development of sett roots from the bottom to the top node in a three-budded sett, the largest quantity of roots being formed by the bottom node. With the production of shoot roots, these sett roots soon die. Before the operation of earthing, roots penetrate through the whole mass of soil in the ridge which contains much of the assimilable nitrogen. The most active period from the standpoint of the development of roots is the grand period of growth of the plant, when there is a profuse branching of roots with an increase in their depth penetration. This does not, however, exceed 36 in. in this soil inclusive of the earthed-up portion in spite of diverse treatments.

(2) The effect of the soil type is quite pronounced on the development of both roots and shoots. Even in the same soil type, there is a progressive fall in weights of roots with an increase in the depth of soil, which is traced to the deficiency of oxygen in lower depths. This deficiency appears to be accentuated in the *chopan* soil (alkali soil) in which the root-system is still restricted under quite similar treatments.

(3) Experiments with varying quantities of water show that higher watering tends to produce a superficial root-system and also create partially waterlogged conditions, adversely affecting the growth of roots and shoots in the case of Pundia and not in POJ 2878, thus bringing out varietal differences in this respect. The stoppage of water till permanent wilting when the plants were three months old has encouraged lateral spread of roots with very little increase in depth penetration. If, however, delayed waterings, such as irrigation at an interval of 20 days instead of the usual ten days, are continued throughout the life-cycle of the plant, the root-system tends to be less superficial than in the normal treatment although the total depth of penetration remains similar in both the cases.

(4) With the increase in nitrogenous manuring, there is a distinct reduction in the weight of roots and increase in that of shoots. On the other hand, phosphatic fertilizers produce a favourable effect on the development of both roots and shoots, their relation being thus direct. This is very striking in the case of superphosphate and bone-meal when applied in two doses, the first one at planting and the other at earthing-up time. Nicifos has been quite ineffective.

(5) Although plants on the windward side produce larger quantity of roots than those on the leeward side, these roots are thicker and quite superficial. The growth of the plants is, however, poorer and it seems the plants lose much of their energy in the formation of the root-system for anchorage against wind, resulting in their poor growth. This adverse effect of wind can be entirely avoided by providing suitable wind-breaks.

(6) Considerable variation is noticed in the development of roots of different varieties and no relationship of any kind can be established between the weights of their shoots and roots. A study of the drought-resisting power of the different varieties shows that it is mainly circumscribed by their transpiring surface, the quantity of roots and the depth of their penetration playing an important part in the case of varieties having equal transpiring surface.

REFERENCES

Alexander, W. P. (1928). *Rep. Assoc. Hawai Sugar Tech.* 90-91
Basu, J. K. and Sirur, S. S. (1938). *Ind. J. Agric. Sci.* **8**, 637-97
Evans, H. (1934). *Dept. Agric. Mauritius Bull.* **5**
————(1935, 1). *Dept. Agric. Mauritius Bull.* **6**
————(1935, 2). *Emp. J. Expt. Agric.* **3**, 351-62
————(1937). *Dept. Agric. Mauritius Bull.* **12**
————(1938). *Eighth Ann. Rept. Sug. Res. Stat. Mauritius 1937*, 53
————(1939). *Proc. 6th Cong. Int. Soc. Suga. Tech., Lousiana*, 802-8
Hardy, F. (1933). *Trop. Agric.* **10**, 6
Jensen. (1931). *Trop. Plant Res. Foundation, Sci. Contribution* No. **21**
Kulesha (1931). *Med. van het Proef. sta. voor de Java Suiker Ind.* No. **8**
Lee, H. A. (1926). *Hawai. Planter's Rec.* **30**
Lee, H. A. and Weller D. M. (1927). *Rep. Assoc. Hawai Sugar Tech.*, 69-72
Lee, H. A. and Bissinger (1928). *Sugar News* **9**, No. 8
Loeb, J. (1919). *J. Gen. Physiol.* **1**, 337-62, 687-715
Rege, R. D. and Wagle, P. V. (1939). *Ind. J. Agric. Sci.* **9**, 423-56
Stevenson, G. S. (1937). *Emp. J. Expt. Agric.* **5**, 239-47
Thomas, R. (1927). *Agric. J. Ind.* **22**, 138-42
Turner T. W. (1922). *Amer. J. Bot.* **9**, 415-46
Venkatraman, T. S. (1922). *Agric. J. Ind.* **17**, 127
Venkatraman, T. S. and Thomas, R. (1924). *Agric. J. Ind.* **19**, 509
————————(1929). *Mem. Dept. Agric. Ind.* (*Bot. Ser.*) **16**, No. 5
Weaver, J. E. (1926). *Root development of field crops.* McGraw. Hill Book Co., New York
Weller, D. M. (1928). *Rept. Assoc. Hawai. Sugar Tech.*, 93-105
————(1930). *Hawa. Planters' Rec.*
Wolters, W. M. (1929, 1). *Rept. Assoc. Hawai Sugar Tech.*, 141-59
————(1929, 2). *Planter and Sugar Manufact.* **82**, 223-25

A STUDY OF FORECASTING OF COTTON CROP IN THE PUNJAB

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THE forecasting of yield of a crop before harvest is a subject of considerable economic importance in agriculture. In the Punjab the forecasts of cotton are based on the data supplied by the Agricultural and Revenue Departments. They involve two factors—acreage and yield. The former is accurate, while the latter is a personal estimate, and it is believed that the standard yield figures exercise a definite influence on the person responsible for forecasting the yield of the tract in his charge. Examination showed that the forecasts for several seasons were recurring underestimates ; consequently the revision of standard yield figures became necessary. An extensive statistical examination of all the crop-cutting experiments and other data for the period 1932-37 was undertaken, in order to evolve a suitable method for fixing the average yield of cotton for each district and each kind of cotton—*desi* and American, irrigated and unirrigated. The results of this investigation are briefly described in this paper.

CROP-CUTTING EXPERIMENTS

There are 28 districts in the Punjab where cotton is grown and out of these crop-cutting experiments are conducted in 23. Crop-cutting experiments are not, however, conducted for both *desi* and American cottons, and both kinds of cultivation, irrigated and unirrigated, in all the 23 disctricts, but in each district they are conducted for that kind of cotton which forms the major portion of the cotton crop in that district. The total area covered by these tracts in 1932-33 to 1936-37 was 12,087,405 acres out of 12,398,302 for the British districts of the Punjab, i.e. in about 97·5 per cent of the area the crop-cutting experiments were conducted. Hence if the crop-cutting experiments are sufficiently numerous, properly conducted and reported (and consequently are representative of the tracts in which they are made), the out-turn calculated from them will represent almost the whole of the cotton crop in the Punjab.

AVERAGE YIELD PER ACRE BASED ON CROP-CUTTING EXPERIMENTS

In the five years 1932-33 to 1936-37, about 1,500 experiments were conducted, of which 600 were carried out by the Agricultural Department and 900 by the Revenue Department. Out of these 188 experiments were rejected for various reasons. As the number of experiments conducted by the Agricultural and the Revenue Departments each year was small, they were combined for the calculation of average yield for each district. The total number of experiments, together with the district yield figures calculated from them, are given in Tables I, II, and III respectively for *desi* irrigated, *desi* unirrigated, and American irrigated cottons.

TABLE I

Average yield of lint in lb. per acre for each district in different years

(*Desi* irrigated cotton)

District	1932-33		1933-34		1934-35		1935-36		1936-37		5 years (1932-37)		
	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Simple mean	Weighted mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hissar	7	183	9	148	8	171	10	192	10	175	44	174	174
Rohtak	8	176	1	87	7	136	11	171	8	181	35	150	165*
Gurgaon	5	159	1	115	2	128	4	149	4	162	16	143	151*
Karnal	4	155	2	80	2	114	4	182	5	133	17	133	141*
Hoshiarpur	2	207	3	159	2	147	3	165	2	193	12	174	172
Jullundur	13	225	7	151	11	190	12	255	9	271	52	218	223*
Ludhiana	7	290	6	125	9	256	9	266	8	233	39	234	240*
Ferozepur	5	177	5	155	5	138	9	164	5	117	29	150	152
Lahore	11	132	9	123	13	138	8	136	19	142	60	133	135
Amritsar	7	164	5	115	3	139	5	152	5	185	25	151	153
Gurdaspur	2	158	3	122	3	135	1	175	3	174	12	153	149*
Sialkot	6	153	5	138	5	143	3	131	5	165	24	146	148
Gujranwala	6	178	4	153	5	127	5	141	4	136	24	147	149
Sheikhupura	6	116	4	163	6	144	9	162	9	151	34	147	148
Gujrat	2	122	1	122	3	136	1	97	4	157	11	127	136*
Shahpur	9	123	4	122	6	105	5	146	7	126	31	124	124
Montgomery	7	134	10	186	8	178	13	204	6	191	44	179	182
Lyallpur	8	123	17	207	14	155	22	174	30	175	86	167	176*
Jhang	4	137	4	108	1	155	3	129	5	133	17	132	129
Multan	7	129	11	137	13	119	13	114	18	115	62	123	121
Muzaffargarh	6	99	8	119	6	110	7	91	12	104	39	105	105
Dera Ghazi Khan	4	103	3	89	5	80	5	84	9	105	26	92	94

TABLE II

Average yield of lint in lb. per acre for each district for different years

(*Desi* unirrigated cotton)

District	1932-33		1933-34		1934-35		1935-36		1936-37		5 years (1932-37)		
	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Simple mean	Weighted mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rohtak	2	83	1	58	3	82	2	106	6	76	14	81	81
Gurgaon	...	...	1	66	1	54	...	...	1	74	3	65	65
Karnal	1	91	1	41	1	89	2	91	3	77	8	78	79
Ambala	9	147	10	134	6	128	10	122	10	136	45	133	134
Hoshiarpur	6	128	2	142	5	157	4	117	5	147	22	138	138
Jullundur	1	93	1	78	1	103	1	111	...	...	4	96	96
Amritsar	1	68	2	77	2	72	2	85	1	84	8	77	78
Gurdaspur	4	87	4	105	4	74	4	128	2	92	18	97	98
Sialkot	2	67	1	82	2	58	2	99	2	91	9	79	79
Gujrat	...	...	3	73	2	90	1	87	2	87	8	84	83
Dera Ghazi Khan	...	...	...	...	2	74	1	87	3	75	6	79	77

TABLE III

Average yield of lint in lb. per acre for each district in different years

(American irrigated cotton)

District.	1932-33		1933-34		1934-35		1935-36		1936-37		(5 years 1932-37)		
	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Mean yield	No. of expts.	Simple mean	Weighted mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ferozepore	3	141	2	112	2	117	3	130	3	162	13	132	135
Lahore	5	160	5	150	7	179	2	165	21	153	40	161	159
Gujranwala	3	140	3	122	4	138	3	171	5	177	18	150	152
Sheikhupura	6	126	4	155	7	151	11	155	8	162	36	150	151
Gujrat	6	104	5	110	6	159	5	172	4	160	26	141	140
Shahpur	9	104	13	164	9	116	10	146	9	142	50	134	137*
Montgomery	7	150	10	213	9	174	13	204	8	205	47	189	192*
Lyallpur	6	132	17	163	33	146	30	178	40	161	126	156	160*
Jhang	7	111	7	138	7	129	10	155	10	137	41	134	136
Multan	5	103	11	155	14	119	20	123	11	130	61	126	128

Since there is a good deal of variation in the number of experiments conducted each year, the average yield for the five years is given as the weighted mean. For the sake of comparison, however, averages for each district obtained by the simple mean are entered in col. 13 and the places where there is noteworthy difference in average by the two methods are marked (*). The differences are fairly high for Rohtak, Gurgaon, Karnal and Lyallpur, for all of which the weighted mean is greater than the simple mean. Considering the mean yields of each year, we find that some are based on a very small number of experiments. Much reliance cannot be placed on such averages, and they can not truly represent the average yield of the season and the tract concerned. Thus for Rohtak and Gurgaon the figures 87 and 115, based on a single experiment each, are very low as compared with other seasons. In the case of *desi* unirrigated cotton, with the exception of Ambala, the number of experiments for each year for all the districts is very small. In fact, even the total number of accepted experiments for Gurgaon, Jullundur, Dera Ghazi Khan are from three to six—a number too small for obtaining a satisfactory mean value representing the average out-turn of a district. In view of all these facts, we cannot treat the district averages for each year separately, and the total out-turn for the five years has been obtained by multiplying the figures in col. 14 with the total area for five years for each district.

RELIABILITY OF DISTRICT YIELDS

In Tables IV, V and VI are given figures for the study of variability of yield of cotton of a given type in different districts. The standard deviation for each district is obtained from the individual yield figures of the five years after eliminating the effect of seasons by the analysis of variance (where possible). The figures in col. 5 of each of the three tables indicate the limits within which the results may vary owing to random causes, and they can be used as a rough guide for the rejection of doubtful experiments. If an experiment gives a yield lower or higher than the limits specified in this column, it should arouse suspicion, and the result should be rejected after scrutiny, unless there are very special reasons to retain it. In col. 7 is given the percentage error of the mean for the district average based on the number of experiments specified in col. 3. In col. 8 are the suggested numbers of experiments which should be conducted in future in each district if the percentage errors (col. 9) for the district averages thus obtained from such numbers are not to be exceeded. The figures in cols. 7 and 9 are calculated by using a formula $\frac{m^2e^2}{n} = x^2$ given in a previous investigation [Koshal and Turner, 1931]. In this formula, n is the number of experiments, x is the desired accuracy expressed as a percentage of the mean, and m is a factor fo obtaining particular odds. For odds of 19 : 1 ($P=0\cdot05$) m is $1\cdot96$, but as in the present cases, the standard deviations are calculated from the small number of experiments, m has been equated in each case to the value of t corresponding to the number of degrees of freedom on which the standard deviation given in col. 4 is based. Thus for Hissar, 33·4 is based on 39 degrees of freedom (after eliminating the effect of seasons) for which $t= 2\cdot023$. Using this value we get the permissible limits of the experiments as 106—242 (the figures given in col. 5 are rounded to the nearest 5). The percentage error on either side of the mean is given by $\frac{19\times 2\cdot023}{\sqrt{44}}=5\cdot8$. In order to obtain higher accuracy, it is suggested that in future about 60 experiments (or 12 per year) should be conducted. The number of experiments suggested in col. 8 are only moderately higher than those conducted in the quinquennium 1932-37. It may be noted that the large number of experiments indicated in col. 3 for Lahore and Lyallpur is due to the inclusion of experiments conducted by the Settlement Officers at these places. Finally, in col. 10 areas under cotton in each district are expressed as a percentage of the total area under cotton cultivation in the Punjab. It will be noticed that the area for *desi* irrigated cotton is fairly large in Ferozepore, Lahore, Hissar, Montgomery and Lyallpur, while the major portion of the American cotton crop is grown in the districts of Montgomery, Multan, Lyallpur and Shahpur. It is essential to conduct a large number of experiments in these districts, so that a reliable average yield figure may be obtained from them. In fixing this number the variability of yield within a district should be taken into consideration. Thus in Lyallpur, in view of the lesser variablity (S. D. = 19 per cent) 60 experiments would be sufficient to ensure 5 per cent error in the district average, while for the same accuracy the number of experiments in Multan district (S. D. = 25 per cent) should be 80. In Montgomery district, which is equally important, in view of the greater variability (S. D. = 27 per cent) the accuracy of the district yield based on 80 experiments is 6 per cent.

TABLE IV

Reliability of district yields

(*Desi* irrigated cotton)

District 1	District average lb. of lint per acre M 2	No. of experiments conducted in 5 years n 3	Standard deviation S. D. S 4	Permissible limits of experiments $P = \cdot 05$ $M \pm St.$ 5	Per cent S. D. e $e = \frac{S}{M} \times 100$ 6	Percentage error of district average $P = 0 \cdot 05$ x $x = \frac{e.t.}{\sqrt{n}}$ 7	No. of experimentrs suggested n' 8	Percentage error of mean $P = \cdot 05$. $x' = \frac{e.t.}{\sqrt{n'}}$ 9	Percentage of area under cotton cultivation 10
Hissar . .	174	44	33·4	105-240	19	6	60	5	3·52
Rohtak . .	165	35	46·8	70-260	28	10	70	7	2·15
Gurgaon . .	151	16	26·7	95-205	18	9	25	8	0·52
Karnal .	141	17	31·8	75-210	23	12	40	8	1·99
Hoshiarpur .	172	12	33·1	100-245	19	12	20	9	0·10
Jullundur . .	223	52	51·5	120-320	23	6	50	6	1·21
Ludhiana . .	240	39	48·8	140-340	20	6	40	6	1·65
Ferozepore .	152	29	23·8	105-200	16	6	40	5	6·95
Lahore . .	135	60	34·2	70-200	25	6	60	6	6·39
Amritsar . .	153	25	27·8	95-210	18	8	50	5	3·15
Gurdaspur . .	149	12	27·4	90-210	18	11	25	8	0·69
Sialkot .	148	24	36·4	75-220	24	10	50	7	0·87
Gujranwala .	149	24	36·1	75-220	24	10	45	7	1·07
Sheikhupura .	148	34	27·7	95-200	19	6	40	6	1·67
Gujrat . .	136	11	29·9	70-200	22	15	30	9	0·47
Shahpur . .	124	31	40·8	40-210	33	12	60	9	2·24
Montgomery .	182	44	37·1	110-250	20	6	60	5	4·59
Lyallpur . .	176	86	32·1	110-240	18	4	50	5	6·63
Jhang . .	129	17	28·2	70-190	22	11	30	8	0·26
Multan . .	121	62	34·0	55-190	28	7	80	6	3·13
Muzaffargarh .	105	39	27·4	50-160	26	8	50	7	1·27
Dera Ghazi Khan.	94	26	24·9	45-145	26	11	40	9	0·70

TABLE V

Reliability of district yields

(*Desi* unirrigated cotton)

District	District average lb. per acre M	No. of experiments conducted in 5 years n	Standard deviation S. D. S	Permissible limits of experiments $P=0\cdot05$ $M\pm S.t.$	Per cent S. D. e $e=\frac{S}{M}\times 100$	Percentage accuracy of district average $P=0\cdot05$ $e.t$ $x=\frac{e.t}{\sqrt{n}}$	No. of experiments suggested n'	Percentage accuracy of mean $P=0\cdot05$ $e.t$ $x'=\frac{e.t}{\sqrt{n'}}$	Per cent area under cotton cultivation
1	2	3	4	5	6	7	8	9	10
Rohtak	81	14	23·2	30-130	28	16	30	11	0·44
Karnal	79	8	22·4	30-130	28	23	30	12	0·64
Ambala	134	45	39·1	55-210	29	9	60	8	1·71
Hoshiarpur	138	22	44·3	45-230	32	14	40	11	0·83
Gurdaspur	98	18	30·5	35-160	31	15	40	10	0·67
Sialkot	79	9	19·2	35-120	24	18	20	12	0·44
Gujrat	83	8	20·3	35-130	24	20	20	13	0·12

TABLE VI

Reliability of district yields

(American cotton)

District	District average lb. per acre M	No. of experiments conducted in 5 years n	Standard deviation S. D. S	Permissible limits of experiments $P=0\cdot05$ $M\pm S.t.$	Per cent S. D. e $e=\frac{S}{M}\times 100$	Percentage error of district average $P=0\cdot05$ $e.t$ $x=\frac{e.t}{\sqrt{n}}$	No. of experiments suggested n'	Percenatge error of mean $P=0\cdot05$ $e.t$ $x'=\frac{e.t}{\sqrt{n'}}$	Per cent area under cotton cultivation
1	2	3	4	5	6	7	8	9	10
Ferozepore	135	13	37·5	55-215	28	18	30	11	0·41
Lahore	159	40	36·9	85-230	23	7	40	7	0·96
Gujranwala	152	18	41·1	65-235	27	16	30	11	0·91
Sheikhupura	151	36	27·5	95-205	18	6	40	6	2·61
Gujrat	140	26	23·7	90-190	17	8	30	6	1·96
Shahpur	137	50	41·0	55-220	30	9	70	7	5·16
Montgomery	192	47	51·7	90-290	27	8	80	6	9·43
Lyallpur	160	126	30·1	100-220	19	3	60	5	5·87
Jhang	138	41	28·4	80-195	21	7	70	5	3·57
Multan	128	61	32·7	65-190	25	6	80	5	9·46

COMPARISON OF CROP-CUTTING EXPERIMENTS WITH PRESS RETURNS

During the five years 1932-37, the total quantity of cotton pressed in different factories of the Punjab was 5,608,454 bales of 400 lb. The total area under cotton cultivation during the five years was 12,398,302 acres. Using this figure (and ginning percentage 32) we get an average out-turn of 6·87 md. of *kapas* baled from every acre of cotton grown in the Punjab. The average out-turn calculated from crop-cutting experiments is 5·75 mds. of *kapas* per acre or about one md. per acre less than the corresponding figure obtained from press returns. This shows that the district yield figures obtained from the crop-cutting experiments are underestimates and fall far short of the average production in the respective districts. There are several reasons for getting low yield from the crop-cutting experiments. In the first place they are not made in large numbers ; consequently they do not truly represent the average out-turn of the tract in which they are conducted. Secondly, cotton is picked several times at intervals and it is often difficult for a responsible officer to supervise each picking personally. Lastly, it is possible that part of the cotton is given as wages to the picker, thereby reducing the total weight obtained from a given area. It may also be noted that the actual crop produced in any one season may not be identical with the commercial crop of that season because : (*a*) a portion of the cotton grown in the adjoining Indian States may be imported into British territory for ginning and pressing, and *vice-versa*, (*b*) mixing up previous year's cotton crop with the new crop is practised to a certain extent. In order to make allowance for all the factors, the total out-turn calculated from the crop-cutting experiments is compared with that obtained from press returns for the five blocks separately. For the purpose of this study Ferozepore is combined with Jullundur to form one block.

TABLE VII

Approximate cotton crop of the Punjab calculated from crop-cutting experiments and press returns for the quinquennium 1932-37

(In bales of 400 lb. lint)

Block	Total area	Total area under crop-cutting tracts	Out-turn calculated from crop-cutting experiments		Out-turn obtained from press returns	Difference column 5 — column 6	
			For area in (3)	For area in (2)		Bales of 400 lb. lint	Per cent on col. (5)
1	2	3	4	5	6	7	8
Ambala . .	1,486,915	1,456,212	524,462	535,518	627,765	—92,247	—17
Jullundur . .	1,408,842	1,392,115	594,605	611,325	633,567	—22,242	—4
Lahore . .	2,488,774	2,422,025	860,493	884,200	943,396	—59,196	—7
Rawalpindi .	1,308,958	1,233,820	413,520	438,703	486,790	—48,087	—11
Multan . .	5,595,775	5,583,238	2,191,512	2,196,434	2,916,936	—720,502	—33
Total .	12,289,264	12,087,405	4,584,592	4,666,180	5,608,454	—942,274	—20

On comparison of the blocks it is found that the greater differences lie in Ambala and Multan blocks, and these are exactly the blocks which lie adjacent to Punjab States : Bahawalpur adjacent to Multan and Patiala, Jind, Nabha and Malerkotla adjacent to Ambala. Although it is known that some of the cotton produced in these states is being sent out to presses in Ambala division, the amount of cotton so imported cannot be specified on account of the inaccurate estimates made by these states. On the other hand, there is sufficient evidence to show that during the five years about two lakhs of bales were imported from Bahawalpur State to the presses situated in Multan division for ginning and pressing. We can, therefore, deduct 2 lakhs of bales from the total baled crop (for the five years) in Multan division, thereby reducing the discrepancy between crop-cutting experiments and press-returns from 33 per cent to about 24 per cent.

HOME CONSUMPTION OF COTTON

An estimate of the total production of cotton in a province is given by the following formula [I. C. C. C. Enquiry, 1936] :—

Approximate actual crop = (1) Cotton pressed + (2) loose (unpressed) cotton received at spinning mills + (3) net exports of loose cotton (all routes) + (4) village consumption of loose cotton, including *kapas*

Items (2) and (3) are usually very small as compared with (1) which has been dealt with in the last section. Consequently the other important factor is item (4) which relates to the quantity of cotton utilized for domestic purposes, such as hand-spinning, making quilts, mattresses, etc. In order to estimate it, an enquiry was made by the Indian Central Cotton Committee [1936] in all the provinces of India. As a result of this enquiry, the following average figures for home consumption were obtained for the Punjab.

	Per capita consumption in lb. of lint
A. *Desi* cotton	
1. Major cotton-growing tract	3.70
2. Minor cotton-growing tract	2.98
3. Non-cotton growing tract	2.35
B. American cotton	0.135

These figures were used in calculating the total quantity of cotton consumed for domestic purposes. The census of 1931 showed [Dept. Agric. Punjab Rep., 1937] that the population during the preceding ten years had increased by an average of 1·1 per cent annually. Assuming this increase to have continued, home consumption of cotton for the five divisions was calculated, and the results are given in col. 3 of Table VIII. In order to get the total production of cotton in each division (col. 4) these figures are added to the outturn obtained from press returns.

TABLE VIII

Comparison of total out-turn (press returns + home consumption) with estimates obtained by crop-cutting experiments, 1932-37

(In bales of 400 lb. lint)

Division 1	Actual out-turn obtained from press returns 2	Calculated home consumption 3	Total 4	Out-turn calculated from crop-cutting expts. 5	Difference col. 5 & 4: Bales 6	Difference col. 5 & 4: Per cent on average of cols. 4 & 5 7
Ambala	615,210	144,192	771,957	535,518	—236,439	—36
Jullundur	620,896	160,884	794,451	611,325	—183,126	—26
Lahore	924,528	263,580	1,206,976	884,200	—322,776	—31
Rawalpindi	477,054	87,277	574,067	438,703	—135,364	—27
Multan	2,658,597	242,975	2,959,911	2,196,434	—763,477	—30
Total	5,296,285	898,908	6,507,362	4,666,180	—1,841,182	..

REVISED STANDARD YIELD FIGURES OF COTTON

To allow for home consumption and difference as shown by press returns, the district yields obtained from crop-cutting experiments in each division have to be increased by the percentage figures given in col. 7 of Table VIII. Analysis of covariance was applied to the revised figures of production thus obtained, and the corresponding figures calculated from the results of crop-cutting experiments, and in this manner the following three equations have been deduced :—

(1) $Y = 1 \cdot 249X + 15 \cdot 14$ for Ambala block

(2) $Y = 1 \cdot 249X + 5 \cdot 86$ for Jullundur -Lahore block

(3) $Y = 1 \cdot 249X + 6 \cdot 08$ for Shahpur-Multan block,

where X is the average district yield calculated from crop-cutting experiments, $1 \cdot 249$ is the ' average regression within blocks ', and Y is the probable district yield in lb. of lint per acre. The figures (rounded to nearest 5) of average yield in lb. per acre calculated from these equations are presented in Table IX, and these may be regarded as the new quinquennial standard yield figures of cotton for the 23 districts and for the kind of cotton and type of irrigation to which they refer. There still remain five districts and the tracts in 23 districts, where crop-cutting experiments have not been conducted. It may be recalled that these cover only about 2·5 per cent of the total area under cotton cultivation in the British districts of the Punjab. However, the standard yields for these are also included in Table IX, and they have been fixed by comparing the total out-turn obtained from the new standard yields in each of the five divisions with the out-turn calculated from the corresponding figures of the last quinquennium. Thus, if the difference for one division is X per cent, then the standard yield figures of the last quinquennium for the districts and tracts where no crop-cutting experiments have been conducted may be raised by X per cent in order to get the revised standard yield figures for the period 1932-37, for that division.

TABLE IX

*Standard yield * figures of cotton in lb. of lint per acre, in each district of the Punjab for the period 1932-37*

District	*Desi*		American	
	Irrigated	Unirrigated	Irrigated	Unirrigated
1. Hissar	230 (150)	120 (90)	..	..
2. Rohtak	225 (160)	110 (70)	..	..
3. Gurgaon. . . .	210 (140)	90 (70)	..	..
4. Karnal	195 (150)	110 (80)	..	..
5. Ambala	200 (150)	185 (130)	..	..
6. Simla	..	..	..	..
7. Kangra	95 (64)	75 (50)	..	..
8. Hoshiarpur . . .	220 (180)	180 (130)	..	..
9. Jullundur . . .	285 (180)	120 (110)	..	..
10. Ludhiana . . .	305 (190)	120 (82)	..	..
11. Ferozepore . .	195 (110)	90 (60)	175 (115)	120 (80)
12. Lahore . . .	175 (110)	95 (70)	205 (150)	100 (72)
13. Amritsar . . .	200 (150)	100 (90)	..	..
14. Gurdaspur . . .	195 (160)	125 (120)	..	..
15. Sialkot	190 (140)	100 (100)	..	..

TABLE IX—*concld.*

District	*Desi*		American	
	Irrigated	Unirrigated	Irrigated	Unirrigated
16. Gujranwala . . .	190 (110)	95 (70)	195 (170)	125 (90)
17. Sheikhpura . . .	190 (100)	110 (80)	195 (170)	110 (80)
18. Gujrat	180 (110)	105 (80)	180 (120)	125 (90)
19. Shahpur . . .	160 (110)	50 (35)	175 (120)	100 (74)
20. Jhelum	200 (146)	85(61)	..	..
21. Rawalpindi . . .	160 (116)	140 (100)	..	..
22. Attock	150 (110)	70 (50)	..	..
23. Mianwali . . .	110 (80)	70 (50)	..	..
24. Montgomery . . .	235 (120)	105 (70)	245 (140)	120 (80)
25. Lyallpur . . .	225 (140)	..	205 (150)	..
26. Jhang	165 (100)	90 (60)	175 (110)	..
27. Multan	155 (90)	90 (62)	165 (105)	110 (75)
28. Muzaffargarh . . .	135 (90)	75 (50)	..	..
29. Dera Ghazi Khan . .	125 (80)	100 (60)	..	..
Provincial average . .	203 (126)	128 (97)	196 (130)	113 (72)
„ „	193 (123)		195 (130)	

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* The figures in brackets are the last quinquennial standard yields.

The new standard yield figures given in Table IX may be regarded as approximately representing the average production (in lb. of lint per acre) in each district and for each type of cotton. They are considerably higher than the old ones, with the result that the provincial standard yields for *desi* and American cottons are raised from 123 and 130 lb. to 193 and 195 lb. respectively. As the revised district yields will be a guide for future forecasts, it is hoped that the dangers of under-estimation will be reduced.

SUGGESTIONS FOR CONDUCTING THE CROP-CUTTING EXPERIMENTS IN ORDER TO ENSURE MORE SATISFACTORY RESULTS

Since crop-cutting experiments are designed to check the average yield of a district, they must conform to the following two conditions :—

(1) A large number of experiments should be carried out in each district so that every type of soil and climate may be well represented. (2) Each experiment should be conducted in such a manner as to be representative of the tract in which it is conducted.

A number of fields should be selected in an average village in the assessment circle concerned, and from them at least two fields may be taken at random for crop-cutting experiments. Each field may be divided into two parts, and from each part two sampling units may be taken at random, and the produce from each weighed separately. This procedure will ensure adequately both randomization and representativeness. The question of the best size of the sampling unit may be settled by conducting a preliminary experiment (involving different sizes of sampling units) in one district.

Experiments on these lines should first be conducted in five districts—one district selected from each of the five divisions. In addition to the yield, some measurable characters, such as number of plants and of bolls on the plant, height of the main axis, etc. of the growing crop should be recorded. If this is done for a number of years, it would probably be possible to find out definite measurements which are closely related to the yield, and these can subsequently be used for forecasting purposes. Thus for the wheat crop, Yates [1936] has shown that plant number and shoot height are significantly associated with the final yield.

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REFERENCES

Agric. Dept., Punjab (1937). *Ann.Rep., 1937*, p. 83

I. C. C. C. (1936). *General report on nine enquiries into the village or extra-factory consumption of cotton in India, 1933-36*, pp. 2, 8

Koshal, R. S. and Turner, A. J. (1931). *J. Text. Inst.* **22**, T.19

Yates, F. (1936). *Manchester Stat. Soc. Pub.*, p. 21

ENTOMOLOGICAL INVESTIGATIONS ON THE LEAF-CURL DISEASE OF TOBACCO IN NORTHERN INDIA

IV. TRANSMISSION OF THE DISEASE BY WHITE-FLY (*BEMISIA GOSSYPIPERDA*) FROM SOME NEW ALTERNATE HOSTS

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Introduction

Our investigations on the leaf-curl disease of tobacco started in 1935 [Pruthi and Samuel, 1937, 1939] were continued at Pusa (Bihar) during the seasons 1938-39 and 1939-40 on a much more extensive scale than in the previous years, with the object of determining alternate host plants of the leaf-curl virus or viruses and the possibility of transmitting the disease from them to healthy tobacco by the white-fly, *Bemisia gossypiperda* M. and L. Several series of experiments have been performed and they confirm our previous conclusions about the transmission of the disease from sunn-hemp and *Ageratum conyzoides* to tobacco, and *vice versa*. Several additional weeds and cultivated plants have been observed in the environs of Pusa suffering from leaf-curl, reminiscent of the disease in tobacco. Of such numerous new plants investigated, several seem to be important hosts and the results of investigations thereon are reported in this paper.

Some transmission experiments with another species of *Bemisia*, viz. *Bemisia giffardi* Kot., collected from *Jasminum sambac,* were also performed to ascertain whether any other species of *Bemisia,* besides *B. gossypiperda,* could also transmit the disease to healthy tobacco. The results of this investigation are also summarized in the following pages.

Technique, material, etc.

The technique adopted in our previous investigations for encasing the white-fly on the food plants for ensuring its feeding thereon has been slightly modified. In the micro-cage described previously [Pruthi and Samuel, 1939], instead of using a tube open at one end, a tube open at both ends was employed (Fig. 1). The mouth of the tube away from the leaf-surface was covered with a wire-gauze thimble (**a**) which permitted free aeration inside the tube and thus the encased white flies lived much longer, and remained more active than in the old form of the cage.

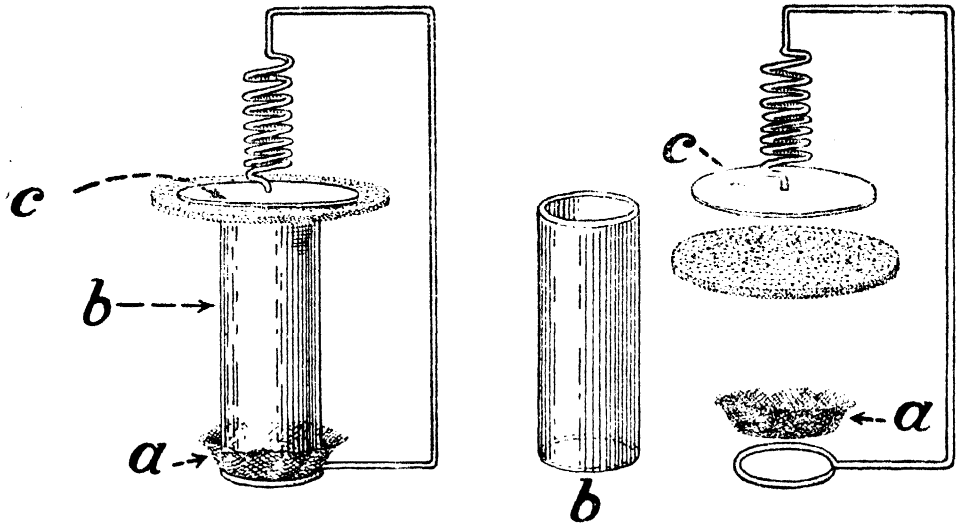


FIG. 1. Micro-cage for feeding white-flies for the transmission experiment. On the right the various parts of the cage are shown separately. [**a**. wire-gauze thimble; **b**. glass tube with both ends open; **c**. spring with disc]

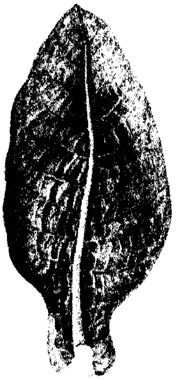
As in previous years, tobacco seedlings (I P hybrid 142) for experimental purposes were raised under strict insect-proof conditions and transplanted in pots containing sterilized soil and were kept covered with muslin bags throughout their life. In order to have seedlings of different ages always available for experiments, tobacco was sown every month for eight months from June to January. Though tobacco is normally harvested at Pusa from the end of January onwards, the inoculated plants under our experiments were kept under observation for noting the appearance of the disease up to the middle of April, when it grew too hot for keeping the plants in the field. The plants continued to give out side-shoots up to about the middle of March.

TRANSMISSION OF THE DISEASE FROM *ZINNIA ELEGANS*

Garden zinnias (*Zinnia elegans*) were noticed during August to October to be suffering from a leaf-curl disease, resembling to some extent the disease in tobacco. *B. gossypiperda* was also observed feeding and breeding on them. It was, therefore, suspected that this plant might prove to be the alternate host of the tobacco leaf-curl virus. In order to test this view, and also to determine whether the white-fly could transmit the disease from zinnia to tobacco four series of experiments were performed during September to January in1938-39 season, and eight series in 1939-40, the particulars and result of which are summarized in Table I.

In 1938-39, the percentage of successful transmission varied from 47 to 87, the maximum being in the case of series ii. In this series, 13 out of 15 plants, which were about eight weeks old and had been inoculated on 8 November, developed leaf-curl in 18-39 days.

The minimum number of white-flies and the minimum period of their feeding, tested for successful transmission, were one specimen (series iii) and one hour (series ii) respectively



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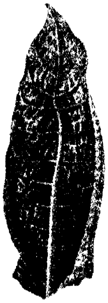

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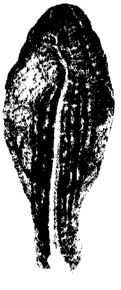

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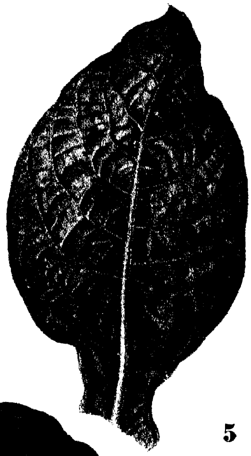

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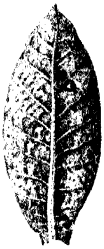

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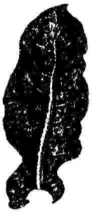

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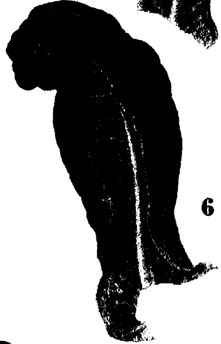

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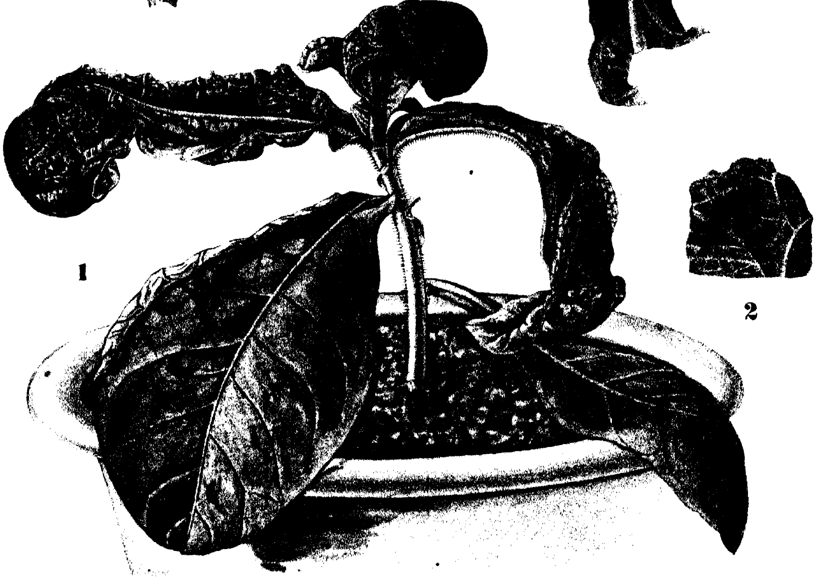

1

2

1. A tobacco plant in which disease was produced by experiment, using diseased zinnia as source of infection. **2.** A portion of leaf of the above plant magnified. **3.** A leaf of a similarly diseased plant. **4.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Euphorbia hirta* as source of infection. **5** and **6.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Vernonia cinerea* as source of infection. **7.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Sida rhombifolia* as source of infection. **8** and **9.** A leaf of a tobacco plant in which disease was produced by experiment, using diseased *Scoparia dulcis* as source of infection

TABLE I

*Particulars of experiments performed to transmit the disease from zinnia to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
						1938-39				
(*i*)	10-11 Sept. 1938 .	8½	4	12—18	17	3	$\frac{12}{17}$	38	75	3, *A*
(*ii*)	8 Nov. 1938 . .	8	15	3—9	1—7	13	$\frac{3}{1}$	18—37	87	6, *DX* ; 2, *C* ; 3, *B*
(*iii*)	7-8 Dec. 1938 . .	8	15	1—20	16	7	$\frac{1}{16}$	22—35	47	2, *D* ; 2 , *DX* ; 3, *X*
(*iv*)	5-7 Jan. 1939 . .	8	6	3—24	8—16	5	$\frac{3}{8}$	27—38	83	2, *DX* ; 3, *BX*
						1939-40				
(*i*)	4 Aug. 1939 . .	11	11	2—16	1	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*ii*)	2 Sept. 1939 . .	11	8	3—8	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	14-15 Sept. 1939 .	9	10	2—6	22	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	24-25 Oct. 1939 .	10	19	1—15	4½—24	4	$\frac{1}{4\frac{1}{2}}$	25—72	21	4, *X*
(*v*)	11-12 Nov. 1939 .	8	13	1—12	7—21	6	$\frac{3}{7}$	26—30	46	2, *C* ; 3, *C* & *D* ; 1, *A* & *D*
(*vi*)	4-5 Dec. 1939 . .	7	22	4—16	6½—22½	1	$\frac{8}{22\frac{1}{2}}$	29	5	1, *C* ?
(*vii*)	7 Dec. 1939 . .	8	6	5—11	5½	1	$\frac{9}{5\frac{1}{2}}$	30	17	1, *C*
(*viii*)	27 Dec. 1939 . .	6	10	4—15	6	2	$\frac{10}{6}$	37	20	Type not formed

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* None of the controls of the various series developed leaf-curl disease

The most common type of leaf-curl produced in tobacco was *D*, often mixed with *X*, but sometimes *A*, *B* and *C* types were also produced. A typical tobacco plant and leaves of some other plants in which disease was thus produced by experiment are shown in Plate XVII, figs. 1-3.

Transmission experiments with zinnia as the source were repeated during the 1939-40 season, when no less than 99 infections under eight series were carried out from August to December (Table I). The highest percentage of successful transmission was, however, 46 only (series v). The common types of disease produced were *B*, *C*, *D* and *X*.

From the foregoing, it is evident that *Zinnia elegans* is an important alternate host of the tobacco leaf-curl disease, especially of *B*, *C*, *D* and *X* types, and that the white-fly can transmit the disease easily from this host to healthy tobacco.

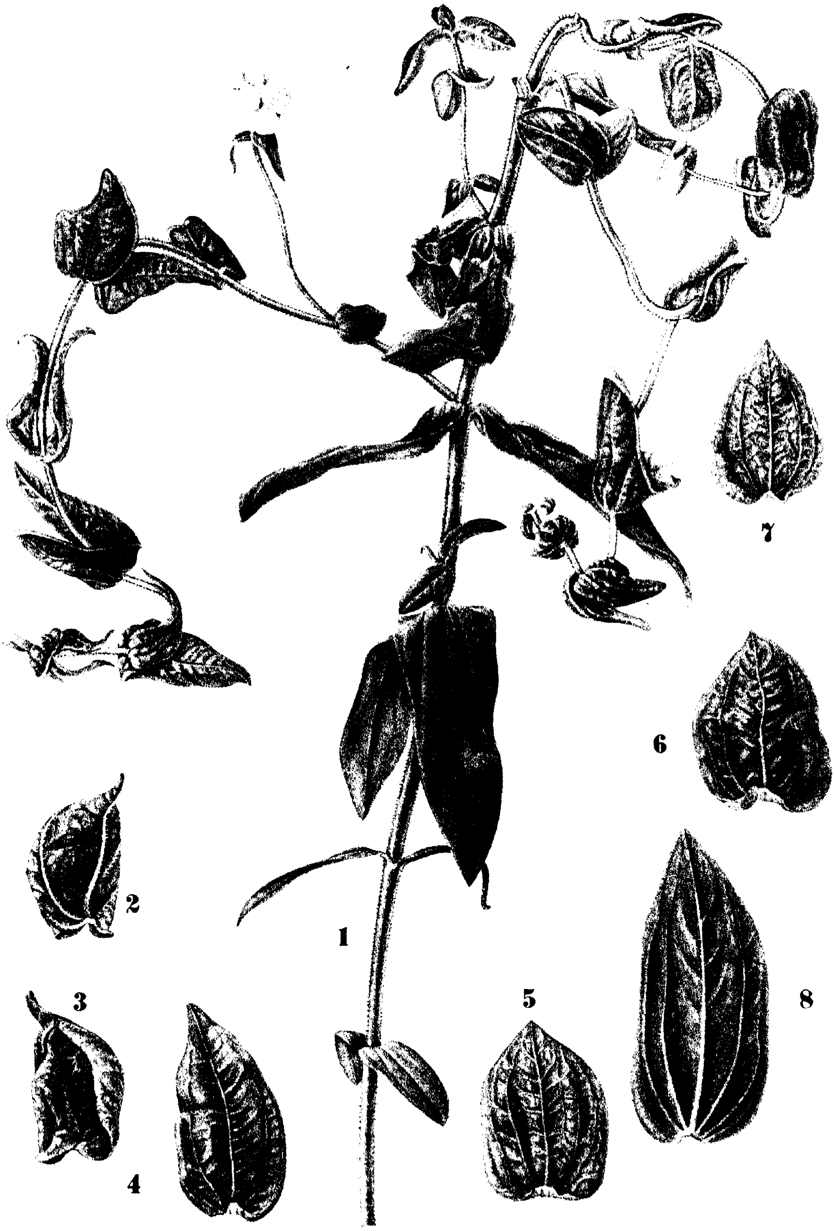
Zinnias are planted in gardens in north Bihar in the month of June soon after the early rains. Leaf-curl generally appears in them from August to October and persists up to January. Tobacco is planted in the field during the last week of September or early in October. Therefore in nature, diseased zinnias seem to act as an important source of infection for the tobacco crop.

TRANSMISSION OF THE DISEASE BACK TO ZINNIA FROM TOBACCO AND SOME OTHER PLANTS

In order to determine whether the leaf-curl disease could be transmitted back to *Zinnia elegans* from tobacco, eight transmission experiments, the results of which are summarized in Table I-A, series i, were performed on 4-5, August, 1939 on four-weeks old healthy zinnia seedlings. Diseased tobacco plants of the previous season which had developed *DX* type were utilized for inoculation purposes. One to five white-flies which had been allowed to feed on the source for 18 hours were introduced on each zinnia plant. After 11-29 days, seven out of eight inoculated plants developed typical leaf-curl (Plate XVIII, figs. 1-4).

Since some weeds, viz. *Vernonia*, *Scoparia*, *Euphorbia*, etc. were frequently noticed near the zinnia plants at Pusa, exhibiting symptoms of some leaf-curl disease, it was suspected that the disease could perhaps be transmitted to zinnias from these weeds also by means of the white-fly. To test this hypothesis, about 26 inoculations, the details of which are given in Table I-A, series ii-iv, were performed in August on healthy zinnia seedlings about four weeks old, using the diseased weeds, named above, as sources. In the case of *Vernonia* to *Zinnia*, all the 12 seedlings inoculated developed severe leaf-curl symptoms. In the case of *Scoparia* to *Zinnia* and *Euphorbia* to *Zinnia*, five out of seven inoculated plants became diseased. The structure of the leaves of zinnia plants in which disease was produced by experiment with the weeds mentioned above as sources of infection are shown in Plates XVIII, figs. 5-7.

Mathur [1933] has shown that *B. gossypiperda* can transmit leaf-curl from diseased to healthy zinnias. To confirm this, 14 healthy seedlings were inoculated each with 1-10 white-flies after they had been allowed to feed on diseased zinnia for 18 hours. All the plants so inoculated developed severe symptoms of leaf-curl in 11-29 days. It is not presumed that the virus at Pusa is the same as at Dehra Dun.



1. A plant of *Zinnia elegans* in which disease was produced by experiment, using diseased tobacco as source of infection. **2** and **3.** Leaves of the same, magnified. **4.** Leaf of another zinnia plant similarly diseased. **5** to **7.** Leaves of zinnia plants in which disease was produced, using diseased *Euphorbia*, *Scoparia* and *Vernonia* as source of infection, respectively. **8.** Leaf of a healthy zinnia plant

TABLE I-A

Particulars of experiments performed to transmit the disease to Zinnia elegans *from various plants (1939-40)**

Serial No.	Time of experiment and type of source of inoculation	Age of zinnia infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					Tobacco to zinnia					
(*i*)	4-5 Aug. 1939 (*DX*) .	4	8	1—5	18	7	$\frac{1}{18}$	11—29	87	Type is like that which occurs in nature
					Vernonia cinerea to zinnia					
(*ii*)	7-8 Aug. 1939 .	4	12	5—7	14	12	$\frac{5}{14}$	21—23	100	Do.
					Scoparia dulcis to zinnia					
(*iii*)	6-7 Aug. 1939 . .	4	7	1—5	22	5	$\frac{1}{22}$	15—34	71	Do.
					Euphorbia hirta to zinnia					
(*iv*)	6-7 Aug. 1939 .	4	7	2—5	20	5	$\frac{2}{20}$	27	71	Do.
					Zinnia to zinnia					
(*v*)	4-5 Aug. 1939 . .	4	14	1—10	18	14	$\frac{1}{18}$	11—29	100	Do.

* None of the controls of the various series developed leaf-curl disease

From the foregoing it is evident that zinnia could act not only as an alternate host of tobacco virus, but could also receive infection of the disease back from tobacco. Furthermore, zinnia itself has three other important alternate hosts of the virus, viz. *Vernonia*, *Scoparia* and *Euphorbia*, from which it gets infected, besides itself acting as an independent source of infection to healthy zinnia in the field.

TRANSMISSION OF THE DISEASE FROM *SOLANUM NIGRUM* TO TOBACCO

Solanum nigrum is also an important food plant of the white-fly at Pusa, and it shows symptoms of a leaf-curl disease. It is a very common weed in North Bihar, particularly near tobacco fields. Transmission experiments were performed to determine whether this plant was also an alternate host of tobacco leaf-curl virus. During 1938-39, four series of experiments were performed in which 55 tobacco seedlings were inoculated, using diseased plants of *Solanum nigrum* collected from the field as source of infection. The work was repeated in 1939-40 and 15 transmission experiments were performed. The results of experiments are given in Table II.

An examination of Table II will show that in 1938-39, the percentage of successful transmission was some times very high, 94-100 per cent (series i and ii). The experiments in these series were performed during July and August. In 1939-40, when all the experiments were done in December and January, the percentage did not go higher than 20-30.

Thus *S. nigrum* is another important alternate host of the tobacco leaf-curl virus of *B*, *C*, *D* and *X* types. It may be stated, however, that the incidence of the disease in *S. nigrum* at Pusa is generally very low, but the few plants which suffer from leaf-curl do so very severely. Such plants can be easily destroyed from the neighbourhood of tobacco crops.

TRANSMISSION OF THE DISEASE FROM *EUPHORBIA HIRTA*

Euphorbia hirta is also one of the common weeds in North Bihar. It also suffers from a leaf-curl disease and is a host of the white-fly. Between July and October 1938, five series of transmission experiments with diseased plants of this weed collected from the field as the source of inoculations were performed on 6-10 weeks old tobacco seedlings. Similarly six series of experiments involving 58 inoculations were performed in 1939. The results of the two years' work are summarized in Table III. An examination of the table will show that the maximum percentage of infection was 67 in 1938-39 (series i) and 70 in 1939-40 (series iv). The experiments under these series were performed in July and October respectively.

The general type of disease developed was *B* and *C* in combination with *X* (Plate XVII, fig. 4). The minimum number of white-flies tested which transmitted leaf-curl was one, and the minimum feeding period tested for successful transmission was six hours. The incubation period of the disease varied from 11 to 64 days.

TRANSMISSION OF THE DISEASE FROM *VERNONIA CINEREA*

Vernonia cinerea is a common weed in the neighbourhood of Pusa and serves as a food plant for thewhite-fly. It occasionally suffers from leaf-curl the disease. In 1938-39, 84 transmission experiments under six series, and in

TABLE II

Particulars of experiments performed to transmit the disease from Solanum nigrum *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (Weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
1938-39										
(*i*)	22-26 July 1938 .	10	17	1—15	8—24	16	$\frac{1}{8}$	11—28	94	1, *BX* ; 7, *C* & *D* ; 8, *DX*. One plant of *DX* recovered; 3 plants had large leaf-like enations.
(*ii*)	4-5 Aug. 1938 . .	7	1	3	24	1	$\frac{3}{24}$	20	100	1, *CX*
(*iii*)	11 Oct. 1938 . .	8	12	2—12	8	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	9 Nov. 1938 . .	8	15	1—8	9	1	$\frac{1}{9}$	25	7	1, *X*
1939-40										
(*i*)	8-9 Dec. 1939 . .	8	5	7—11	4½—22½	1	$\frac{11}{4\frac{1}{2}}$	48	20	*Nil*
(*ii*)	5 Jan. 1940 . .	7½	10	5—17	17½	3	$\frac{7}{17\frac{1}{2}}$	27—43	30	*Nil*

*None of the controls developed leaf-curl disease.

1939-40, 68 inoculations under six series were performed with a view to ascertaining if this weed was also an alternate host of tobacco leaf-curl, and whether the white-fly could be the vector concerned. Diseased plants this weed were collected from the field for inoculation purposes. The results of the experiments are summarized in Table IV.

In 1938-39, the highest positive transmission obtained was 27 per cent (series vi). In this series, 15 inoculations were done on eight weeks old tobacco seedlings on 7-8 February. After 23-25 days, four plants, on which 10-15 specimens of white-flies had been introduced, developed leaf-curl symptoms, but two of them ultimately recovered. In 1939-40, the highest percentage of positive transmission obtained was 70 (series iv). In this series, 10 tobacco seedlings, about nine weeks old, were inoculated in October each with 8-20 white-flies after a feeding period of six hours on the diseased source. Seven seedlings developed leaf-curl in 14-41 days. The lowest positive transmission was 10 per cent (series vi). In three series, viz. Nos. (ii), (iii) and (v), no positive results were obtained.

From the foregoing it will be seen that the disease can be transmitted from *V. cinerea* to tobacco by the white-fly, though the percentage of positive transmission is not so high as in the other alternate hosts described in the preceding pages. It may be mentioned that Thung [1934] was also able to transmit leaf-curl from *Vernonia cinerea* to healthy tobacco in Java and obtained a high percentage of positive results. From the examination of results given in Table IV, it is evident that majority of the inoculated seedlings developed *C* and *A* types of leaf-curl, which were sometimes mixed with *X* and *D* types (Plate XVII, figs. 5 and 6). The minimum number of white-flies which successfully transmitted the disease was one, and the minimum feeding period tested for the transmission was six hours.

Diseased plants of *Vernonia* are not of common occurrence at Pusa, but the small number of plants which are infected show symptoms of virulent type of leaf-curl.

TRANSMISSION FROM TOMATO, *LYCOPERSICUM ESCULENTUM*

Tomato in North Bihar frequently suffers from a serious type of leaf-curl resembling bunchy-top of tomato virus 2 [Johnson, 1927] in U. S. A., described by McClean [1931]. Since it is also a favourite food plant of the white-fly, three series consisting of 51 inoculations and the same number of series consisting of 30 inoculations were performed with this plant during 1938-39 and 1939-40 respectively. The results are summarized in Table V. In 1938-39, the percentage of successful transmissions varied from 4 (series iii) to 56 (series ii). In the latter series, 16 tobacco plants, eight weeks old, were inoculated on 10-11 February by means of six to ten white-flies after they had fed for 24 hours on diseased tomato. Nine plants developed leaf-curl, of which five showed *A* type, and two *X* type. Two other plants which showed traces of *X* type, subsequently recovered before the end of the season. The incubation period of the disease was 20-27 days. The minimum number of white-flies tested which transmitted the disease was seven. In 1939-40, the highest percentage of positive transmission was 20

TABLE III

Particulars of experiments performed to transmit the disease from Euphorbia hirta *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	25 July 1938	10	9	2—12	6	6	$\frac{2}{6}$	11—27	67	Plants died before type formation
(*ii*)	25-26 July 1938	6	9	1—15	23	2	$\frac{1}{23}$	10—36	22	1, *CX* ; 1, *C*. *C* recovered
(*iii*)	23 Aug. 1938	10	10	4—20	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	1-3 Sept. 1938	7	12	1—11	24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	6-7 Oct. 1938	8	10	5—20	22	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
					1939-40					
(*i*)	27-28 July 1939	10½	7	2—8	14	2	$\frac{5}{14}$	14—25	29	2, *X*
(*ii*)	1 Sept. 1939	11	11	2—11	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	13 Sept. 1939	8½	10	3—6	7½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	17 Oct. 1939	9	10	6—16	6	7	$\frac{10}{6}$	14—64	70	6, *BX* ; 1, *X*
(*v*)	10-11 Nov. 1939	8	10	7—16	7—11	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vi*)	29 Dec. 1939	6½	10	7—14	6	1	$\frac{11}{6}$	4	10	Type not formed

* None of the controls in the variou s series developed leaf-curl disease.

TABLE IV

Particulars of experiments performed to transmit the disease from Vernonia cinerea *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
						1938-39				
(*i*)	5-7 Sept. 1938 . .	8	12	1—18	38	2	$\frac{1}{38}$	17—23	17	2, *X* ; large enations present
(*ii*)	10-11 Oct. 1938 .	8	12	3—12	24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	6-7 Nov. 1938 . .	8	15	1—25	1—17	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	11-14 Dec. 1938 .	9	15	4—15	24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	2-3 Jan. 1939 . .	7½	15	3—20	24	1	$\frac{10}{24}$	50	7	Recovered
(*vi*)	7-8 Feb. 1939 . .	8	15	8—40	24	4	$\frac{10}{24}$	23—25	27	2, *X* ; 2 other plants recovered
						1939-40				
(*i*)	27-28 July 1939 .	10	7	1—12	14	1	$\frac{6}{14}$	14	14	*X*
(*ii*)	30-31 Aug. 1939 .	11	10	2—8	6	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	12 Sept. 1939 . .	8½	10	3—8	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	17 Oct. 1939 . .	9	10	8—20	6	7	$\frac{9}{6}$	14—41	70	4, *CX* ; 1, *A* & *C* ; 2, *A* & *D*
(*v*)	10 Nov. 1939 . .	10	10	6—16	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vi*)	5-29 Dec. 1939 . .	7—7½	21	6—13	6—7	2	$\frac{12}{7}$	25—35	10	1, A

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* None of the controls of the various series developed leaf-curl disease.

(series i) when 10 tobacco seedlings, about nine weeks old, were inoculated on 16-17 November each with 5-14 white flies, which had fed on the diseased source for 21 hours. The incubation period of the disease was 22-29 days.

TRANSMISSION OF THE DISEASE FROM *LAUNEA ASPLENIFOLIA*

Launea is one of the most common perennial weeds in tobacco fields in North Bihar. It seems to have two great flushes in the year, i.e. one during February to April and another during July to September. Leaf-curl appears in this weed chiefly in the colder months, viz. November to February. Three series of transmission experiments in 1938-39 and six series in 1939-40 were performed with this host plant, the results of which are summarized in Table VI. In 1938-39, the highest percentage of positive transmission was 50 (series iii) when 10 inoculations on nine weeks old tobacco plants were done on 12-13 February. Twelve to twenty-three white-flies which had been allowed to feed on diseased weed for 24 hours before were transferred to healthy tobacco seedlings. Five plants developed leaf-curl in 20-25 days. The minimum number of white-flies tested for the transmission of the disease was five. In 1939-40, the maximum percentage was 44 (series v), when nine tobacco plants, eight weeks old, were inoculated on 7 December. Four plants showed positive reaction, but the exact type of the disease could not be distinguished. The incubation period of the disease was 35-57 days. The minimum number of white-flies and their minimum feeding period tested for successful transmission of the disease was 2 and 5½ hours respectively.

TRANSMISSION OF THE DISEASE FROM *SIDA RHOMBIFOLIA*

Sida rhombifolia is also a common weed (annual) in North Bihar, which grows profusely on the field bunds, river banks and road sides. The season of its growth begins in the rainy months of July-August and lasts up to the end of February after which it practically dies out. Disease generally appears in this weed during autumn. For inoculation purposes, diseased plants were collected from the field, and six series of experiments in 1938-39 and eight series in 1939-40 were performed, the results of which are summarized in Table VII.

In 1938-39, the highest percentage of successful transmission was 39 (series i), when 23 tobacco plants, seven to eight weeks old, were inoculated by introducing per plant 3-31 white flies which had fed for 12-15 hours on the diseased weed. Nine plants on which six specimens had been put showed reaction. Three of these developed *A* type, one *AX* and one *C*, while the remaining four practically recovered by the end of the season. The minimum number of white-flies tested for the transmission of the disease was three. The incubation period of the disease was 19-45 days. In 1939-40, the maximum positive transmission was 20 per cent (series iv), when 21 tobacco plants, about ten weeks old, were inoculated on 26-30 October each with 1-32 white-flies which had fed for 17-24 hours on diseased source. The minimum number of flies which transmitted the disease was one. The incubation period was 28-71 days, and all the plants developed *X* type of leaf-curl.

TABLE V

Particulars of experiments performed to transmit the disease from tomato, Lycopersicum esculentum, *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
						1938-39				
(*i*)	7-9 Jan. 1939 . .	8	10	12—32	24—48	2	$\frac{29}{48}$	35—37	20	1, *B* ?; 1, *X*
(*ii*)	10-11 Feb. 1939 .	8	16	6—10	24	9	$\frac{7}{24}$	20—27	56	5, *A* ; 2, *X* ; other plants having traces of *X* recovered
(*iii*)	29-30 Mar. 1939. .	11	25	9—15	24	1	$\frac{13}{24}$	31	4	1, *X*
						1939-40				
(*i*)	16-17 Nov. 1939 .	9	10	5—14	21	2	$\frac{9}{21}$	22—29	20	Profuse undulations noticed on lowerleaves of infected plants
(*ii*)	4 Dec. 1939 . .	7	10	9—24	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	27 Dec. 1939 . .	6	10	5—14	6	2	$\frac{12}{6}$	42	*Nil*	Traces of leaf-curl symptoms visible

* None of the controls developed leaf-curl disease.

TABLE VI

Particulars of experiments performed to transmit the disease from Launea asplenifolia *to tobacco* *

Serial No. 1	Time of experiment	Age of tobacco infected (Weeks) 3	No. of plants infected 4	No. of white-flies used 5	Period of feeding (hours) 6	No. of plants which developed disease 7	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$ 8	Incubation period of disease (days) 9	Percentage of successful transmission 10	Type of disease appearing and remarks 11
					1938-39					
(*i*)	2-3 Sept. 1938	7	6	1—25	24	2	$\frac{5}{25}$	39—46	33	1, *X*; 1 recovered
(*ii*)	10 Jan. 1939	8½	6	9—15	6	*Nil*	*Nil*	*Nil.*	*Nil*	*Nil*
(*iii*)	12-13 Feb. 1939	9	10	12—23	24	5	$\frac{12}{24}$	20—25	50	Type not formed
					1939-40					
(*i*)	28-29 July 1939	10	9	2—9	21	1	$\frac{2}{21}$	9	11	*DX*
(*ii*)	1 Sept. 1939	11	11	6—13	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	16 Sept. 1939	9	10	4—11	7	1	$\frac{6}{7}$	23	10	*C* ?
(*iv*)	16-17 Nov. 1939	9	10	9—15	22	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*v*)	7 Dec. 1939	8	9	6—12	5½	4	$\frac{6}{5\frac{1}{2}}$	35—57	44	Type not formed
(*vi*)	28 Dec. 1939	6½	10	7—13	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*

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* None of the controls of the various series developed leaf-curl disease.

TABLE VII

Particulars of experiments performed to transmit the disease from Sida rhombifolia *to tobacco* *

Serial No.	Time of experiment	Age of tobacco infected (Weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
					1938-39					
(*i*)	3-5 Sept. 1938 . .	7—8	23	3—31	12—15	9	$\frac{6}{12}$	19—45	39	3, *A*; 1, *AX*; 1, *C*; 4 plants recovered
(*ii*)	12-15 Oct. 1938 .	8—9	24	2—25	8½—24	*Nil*	*Nil*	*Nil*	*Nil.*	*Nil*
(*iii*)	6-7 Nov. 1938 . .	8	30	2—9	1—6	2	$\frac{3}{1}$	40—41	7	1, *CX*
(*iv*)	13-19 Dec. 1938 .	9	30	2—22	24	2	$\frac{4}{24}$	28—31	7	1, *CX*
(*v*)	4-7 Jan. 1939 . .	7½	19	2—25	24—48	3	$\frac{7}{24}$	29—42	15	Type not forme
(*vi*)	8-9 Feb. 1939 . .	8	20	4—37	19—24	6	$\frac{11}{19}$	22—27	30	1, *X*
					1939-40					
(*i*)	26-27 July 1939 .	10	10	3—12	5½—22½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*ii*)	26-30 Aug. 1939 .	25	13	2—14	14—24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	13-17 Sept. 1939 .	8½—9	20	2—7	7—23	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iv*)	26-30 Oct. 1939 .	10½	21	1—32	17—24	4	$\frac{1}{17}$	28—71	20	4, *X*
(*v*)	14-15 Nov. 1939 .	9	20	3—16	8½—20	2	$\frac{9}{20}$	31—45	10	1, *C*; 1, *X*
(*vi*)	6 Dec. 1939 . .	8	10	6—10	6½	1	$\frac{6}{6½}$	28	10	*Nil*
(*vii*)	28 Dec. 1939 . .	6	12	5—13	6½	2	$\frac{12}{6½}$	41—78	17	*Nil*
(*viii*)	4-5 Jan. 1940 . .	7½	9	6—13	17½	2	*Nil*	*Nil*	*Nil*	*Nil*

---

* None of the controls of the various series developed leaf-curl disease.

It will be seen from Table VII that the maximum percentage of positive transmissions were obtained when inoculations were done during September or February. The common types of disease developed were *A* or *CX* ; a leaf of a plant suffering from latter type is shown in (Plate XVII, fig. 7). The minimum number of white flies tested and found successful for the transmission of disease was one individual and the minimum feeding period tested for the successful transmission was one hour.

It may be stated here that *Sida* was suspected to carry the leaf-curl virus of tobacco in Africa also [Storey, 1935].

TRANSMISSION OF THE DISEASE FROM *SCOPARIA DULCIS*

Forty-eight transmission experiments under six series, particulars of which are given in Table VIII, were performed between July and December 1939, using diseased *Scoparia* collected from the field as the source of inoculation. The age of healthy tobacco inoculated varied from 8 to 14 weeks. Only in one series (v) positive transmissions were obtained. In this, ten tobacco seedlings, about nine weeks old, were inoculated on 18-19 October each with 4-13 white-flies which had fed for 24 hours on diseased weed. Four seedlings on which 6-13 white flies had been introduced, developed leaf-curl of *X* type in 46-95 days (Plate XVII, figs. 8 and 9).

TRANSMISSION OF THE DISEASE FROM TOBACCO TO TOBACCO

In our previous investigations [Pruthi and Samuel, 1939], we found that it was not easy to transmit leaf-curl from diseased tobacco to healthy tobacco with the help of the white-fly. However, during 1939-40, we were able to get much higher percentage of successful tarnsmissions than in the past. Fifty-seven transmission experiments were performed under seven series, particulars of which are given in Table IX. In three series (i, iii and iv) positive results were obtained, the percentages of successful transmission being 8, 44 and 90 respectively. In series iv giving maximum positive results, ten inoculations were done on 16-17 November, when healthy tobacco seedlings under experiment were nine weeks old. Tobacco plant suffering from leaf-curl of *D* type was used as the source of infection. Nine plants developed leaf-curl. The general type of disease was *D*, but in some plants, it was mixed with other types. The minimum number of white-flies tested and found successful in the transmission was two.

NUMBER OF WHITE-FLIES AND THE PERIOD OF THEIR FEEDING ON DIFFERENT DISEASED PLANTS NECESSARY FOR THE TRANSMISSION OF LEAF-CURL, THE INCUBATION PERIOD OF THE DISEASE, ETC.

In a previous paper [Pruthi and Samuel, 1939], it was shown that the minimum number of white-flies tested and found successful for the transmission of the disease from sunn-hemp and *Ageratum* to tobacco was 5 and 1 respectively. Similarly it was shown that the white-fly could transmit leaf-curl after five or six hours' feeding, shorter periods having not been tested. Experiments carried out during the last two years throw further light on these problems. In Table X, the minimum number of white-flies tested and found

TABLE VIII

Particulars of experiments performed to transmit the disease from Scoparia dulcis *to tobacco**

Serial No.	Time of experiment	Age of tobacco infected (Weeks)	No. of plants infected	No. of white-flies used	Period of feeding (hours)	No. of plants which developed disease	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$	Incubation period of disease (days)	Percentage of successful transmission	Type of disease appearing and remarks
1	2	3	4	5	6	7	8	9	10	11
(i)	26-27 July 1939	10	9	6—12	5½—22½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(ii)	26 Aug. 1939	14	4	5—6	14	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(iii)	29-30 Aug. 1939	11	10	2—7	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(iv)	12 Sept. 1939	8	10	2—6	7	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(v)	18-19 Oct. 1939	9	10	4—13	24	4	$\frac{6}{4}$	46—95	40	4, *X*
(vi)	18 Dec. 1939	8	5	6—10	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*

* None of the controls of the various series developed leaf-curl disease.

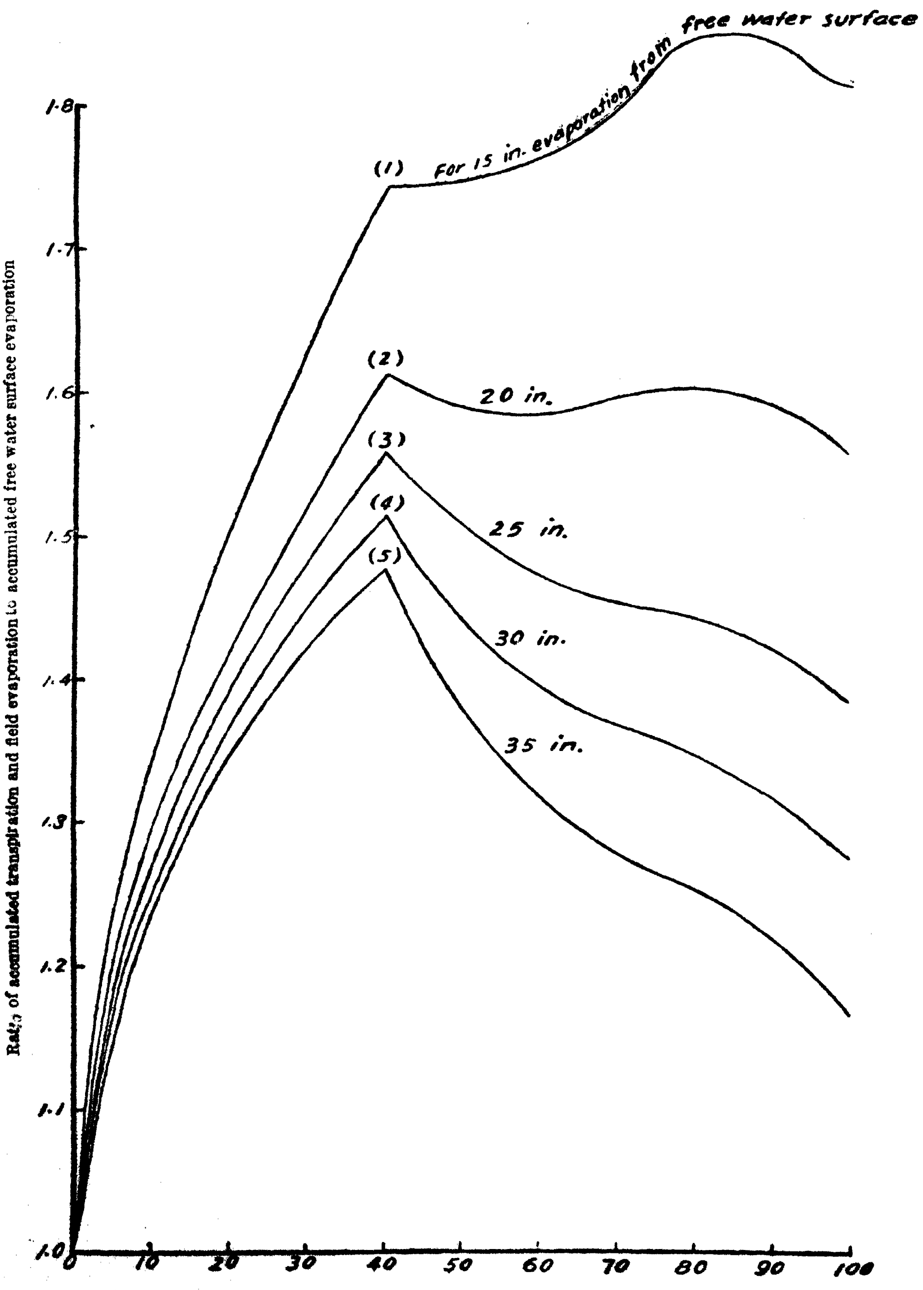

Fig. 7. Distribution graph for field evaporation and transpiration

TABLE

Comparison of observed and computed total

Country	Location	Period	Soil condition	Approximate date of irrigation		
				First irrigation	Beginning of submergence	End of submergence
U. S. A.	Sacramento Valley, California	1916—1918	Capay clay	Ave. April 21 From April 14 to May 22	Ave. June 11 From May 19 to June 12	Ave. Sept. 30 From Sept. 27 to Oct. 30
			Willows clay adobe			
			Willows clay			
			Stockton clay adobe			
			Sacramento clay			
			Tehama clay loam and clay			
			Vina clay loam			
			Willows loam & clay			
			Willows loam			
			San Joaquim loam			
	Biggs, Calif.	1914—1917	Stockton clay adobe	April 15	June 9	Sept. 30
	Arkansas	1928—1929	Surface soil is silt lam. Subsoil is impervious clay	May 20	July 1	Sept. 30
	Texas					
	Louisiana	1917—1919				
China	Wukiang, Kiangsu	1934—1935	Clay	May 9	June 1	Aug. 16
	Wuchin, Kiangsu	1928—1935	Impervious clay	May 9	June 11	Sept. 20
	Canton, Kwangtung	1927—1929	Clay loam	April 20	May 5	July 28
	Canton, Kwangtung	1927—1929	Clay loam	July 21	Aug. 5	Nov. 3
Indo-China	Thank-Hoa, Annam		Clay	June 11	July 1	Nov. 30
Java	Tangerang		Clay	Nov.		Mar.
India	Maruteru	1937	Clay	June 26	July 11	Nov. 27

VIII

net duty of water for rice in various countries

Average length of irrigation season, days			Observed total evaporation during submergence (in.)	Average seasonal temperature (°F.)	Daily loss of seepage obtained from fig. 6 at 70°F(a) (in.)	Computed total net duty of water (in.)	Observed total net duty of water (in.)	Variation from observed value (per cent)	Remarks
Prior to submergence	During submergence	Total							
Ave. 51	Ave. 112	159	Ave. 85·13 (It is the average value from 1926 to 1936 a Davis)	70·0	0·017	48·1	47·5	+ 1·3	(a) All daily losses of seepage are the average values which are obtained from fig. 6. (b) The correction of seepage for the effect of temperature is 1¼ per cent per degree Fahrenheit. (c) In Annam there was no temperature record and therefore no correction is made. (d) In Wukiang due to the new rice field the seepage was very high and in Canton due to high ground water table the seepage was very low, therefore the original seepag data are used in these special cases. (e) In these three States, all conditions in the rice field were nearly the same. There were no complete records at hand and can only check with 31″—37″ which was estimated by Prof. W. B. Gregory. The total water used during submergence in Arkansas was 29·85″ and in Louisiana was 28·04.″
		154			0·017	48·1	50·6	— 4·9	
		168			0·075	58·1	61·0	— 4·8	
		157			0·075	57·3	61·6	— 7·0	
		167			0·075	58·0	68·6	—15·4	
		172			0·300	97·1	97·5	— 0·4	
		153			0·300	91·5	97·5	— 6·2	
		155			0·300	92·0	80·2	+ 14·8	
		170			0·450	122·0	112·6	+ 8·4	
		174			0·450	123·9	140·5	—11·8	
55	114	169	29·42	70·0	0·075	54·6	54·4	+ 0·6	
41	92	120	15·72	80·1	0·017	34·09 (b)	34·0 (e)	+ 0·4	
23	77	100	12·79	81·1	0·154 (d)	44·40	No		
33	102	135	20·00	81·1	0·017	37·91 (b)	38·00	— 0·2	
15	84	99	11·05	81·4	0·041 (d)	31·25	24·67	+ 26·6	
15	91	106	17·34	80·0	0·071 (d)	40·63	31·12	+ 30·6	
20	153	173	20·08		0·075	48·50 (c)	51·33	— 5·6	
49	84	133	14·90	80·0	0·075	42·25 (b)	44·01	— 4·0	
15	139	154	31·59	80·8	0·075	57·20	59·65	— 4·0	

TABLE IX

Computation of duty of water at Biggs Rice Field, California, by distribution graph

1	2	3	4	5	6	7	8	9	10	11	12	13	14
			Per cent of time during period of submergence		Observed evaporation from free water surface								
Month	Approximate date of irrigation season	Number of days	Monthly	Accumulated	Monthly (E)	Accumulated ΣE	Ratio of accumulated field evap. and transpiration to accumulated water surface evap.	Accumulated field evap. and transpiration at end of month $\Sigma(Ef+P)$	Field evaporation and transpiration during each month $(Ef+P)$	Seepage for each month (S)	Minimum water required for initial flooding	Total water required for each month	Capacity required Q
		days	Per cent	Per cent	in.	in.	$R = \frac{\Sigma\ (Ef+P)}{\Sigma E}$	in.	in.	in.	in.	in.	c.f.s./acre
April	**Date of first irrigation April 15**	16								1·20	4·00	5·20	0·0137
May		31								2·33		2·33	0·0032
June	**Beginning of submergence June 9**	8 22	19·3	19·3	6·34	6·34	1·357	8·60	8·60	0·60 1·65		10·85	0·0152
July		31	27·2	46·5	9·32	15·66	1·467	23·00	14·40	2·33		16·73	0·0227
Aug.		31	27·1	73·6	7·73	23·39	1·365	31·90	8·90	2·33		11·23	0·0153
Sept.	**End of submergence Sept. 30**	30	26·4	100·0	6·03	29·42	1·275	73·55	5·65	2·25		7·90	0·0111
Total or average		169							37·55	12·69	4·00	54·24	0·0135

The following example shows the method applied to the duty of water at the Biggs Rice Field in California.

Given conditions.

Location : Biggs Rice Field, California, U.S.A.
Soil : Stockton clay adobe.
Average date of irrigation season :
  Date of first irrigation, April 15.
  Date of beginning of submergence, June 9.
  Date of end of submergence, September 30.
Data on evaporation from free water surface :
  Use the mean observed value for the Biggs Rice Field Station from 1914 to 1917.
Length of irrigation season :
  Before submergence 55 days.
  During submergence 114 days.
  Total submergence 169 days.
The steps of the computations are given in Table IX.

CONCLUSIONS

In this paper data has been collected from California, Arkansas, Texas and Louisiana in the United States, Kiangsu and Canton provinces in China Annam in Indo-China, Tangerang in Java, and Madras Province, India. The total net duty of water for rice ranged from 24·67 inches at Canton to 140·5 inches in California.

The principal factors in the consumption of water in rice fields are : (1) field evaporation, (2) transpiration, (3) seepage, and (4) preparation of land or initial flooding. The conditions which have the most important effect upon these factors are : (1) climatic conditions, (2) characteristics of soil, (3) length of irrigation season, (4) ground water table, (5) yield, and (6) method of planting.

The temperature, humidity, and wind velocity are the main factors affecting field evaporation and transpiration in rice fields, as well as evaporation from a free water surface.

The characteristics of the soil have an important effect upon seepage. In the Sacramento Valley, California, the climatic conditions are nearly the same, but the average net duty of water varied from 47·5 inches for Capay clay to 140·5 inches for San Joaquin loam. This difference was due mainly to the varied seepage rates in the different types of soil.

In addition to the type of soil, the ground water table is an important factor in seepage. In Canton, the soil was clay loam, but the average daily loss by seepage for early and late rice was 0·056 inches, which was less than that of other localities owing to the high ground water table. The age of the rice field also may affect the rate of seepage. In Wukiang the soil was clay, but the average daily loss of seepage was 0·154 inch, which was greater than for the same type of soil at Wuchin, because the Wukiang field was new.

The irrigation season not only depends upon the kind of rice but also is affected by the climatic conditions. The average temperature in California is lower than in other rice growing sections and therefore the growing season of rice in that country is longer.

The ratio of accumulated field evaporation to accumulated evaporation from free water surface decreases with the stage of growth of the rice plant after 40 per cent of the total submergence time has elapsed, while the ratio of transpiration to free water surface evaporation increases with the stage of growth up to 85 per cent of the submergence period.

The empirical formula derived is very easily used. The total net duty of water is found directly from free water surface evaporation during submergence season and average daily loss of seepage in the rice field. If there is no evaporation record, the value of the evaporation loss may be obtained by means of evaporation formulas.

The graph of distribution of water use is useful in design to determine the peak of the irrigation water demand or the amount required at any interval of time during the irrigation season.

Suggestions for future observations on rice irrigation water requirements

Although the empirical formula and distribution diagrams developed in this study are believed to be as reliable as was possible to obtain from the data available, better results could have been obtained if more data had been available. It is hoped to secure further data and to continue these studies at a later date.

In order to aid those seeking information on how such experiments should be carried out, the following list of desirable observations has been compiled :

(a) Climatological conditions
  1. Evaporation from evaporation pan
  2. Temperature
  3. Wind velocity
  4. Humidity

(b) Consumption of water in rice fields and the distribution through the entire irrigation season
  1. Field evaporation
  2. Transpiration
  3. Seepage
  4. Preparation of land or initial flooding
  5. Depth of water in rice field

(c) Kind of rice and its growing condition
  1. Kind of rice
  2. Method of planting
  3. Length of growing season
  4. Dry grain produced

(d) Irrigation season
  1. Date of first irrigation
  2. Date of beginning of submergence
  3. Date of end of submergence

(e) Geologic conditions
  1. Mechanical analysis of surface soil
  2. Mechanical analysis or permeability tests of subsoil
  3. Ground water table elevation

APPENDIX

After completing the original paper, the authors received further information concerning rice irrigation from the Bureau of Plant Industry, Department of Agriculture. and Commerce, Philippine Islands, which they feel should be included in the report. Although sufficient data is not available for an investigation of computed value in comparison to those measured, it is believed it will be possible to secure information at a later date.

Experiments to determine the amount of water necessary to mature a normal rice crop were conducted in Alabang on Laguna de Bay, about 18 miles south of Manila, in the province of Rizal, Luzon Island, Philippine Islands. The soil is a black stiff clay, underlaid for the most part with adobe rock. In 1924 and 1926 the loss of water from the heavy clay rice soil of Alabang was determined in 65 paddies with a total area of 12,006 sq. ft. The depth of submergence was approximately 2·95 inches in 1924 and 2·44 inches in 1926. The observations were continued for 16 weeks (August to December) coinciding with the growing period of rice. The loss of water was determined by taking daily readings of the water level in the paddies. The irrigation water came from a well and discharged directly into the field through a pipe. Therefore the losses included only evaporation, transpiration and seepage. As the soil is underlaid by adobe rock, the percolation may be neglected.

In 1924 the total amount of water required for a second rice crop during the dry season was also determined in a rice field with an area of 14,158 sq. ft. The water was used during the irrigation period from January to May. In January a large amount of water was used in the preparation of the land. The soil was submerged slightly early in the month to encourage the growth of weeds and in the latter part of the month to prepare the seed bed.

The total amount of water used in each experiment is summarized as follows:

Year	Irrigation season	Total amount of water used, cubic meters per hectare	Total amount of water used, depth in inches
1924 . . .	Aug. to Dec. . .	8,850	34·8
1926 . . .	Aug. to Dec. . .	9,993	39·2
1924 . . .	Jan. to May . . .	20,136	79·4

BIBLIOGRAPHY

(1) *Irrigation of rice in California*, by Ralph D. Robertson, *Agricultural Experiment Station, University of California, Bulletin* No. **279**, 1917

(2) *Rice irrigation measurement and experiments in Sacramento Valley*, by Frank Adams, *Agricultural Experiment Station, University of California, Bulletin* No. **325**, 1920

(3) *Climatological data: California Section, Weather Bureau, U. S. Department of Agriculture*, 1914—1918

(4) *Experiments in rice culture at the Biggs Rice Field Station in California*, by Jenkin W. Jones, *Department Bulletin* No. **1387**, 1926

(5) *Irrigation engineering*, by Davis and Wilson, p. 151

(6) *Cost of pumping and duty of water for rice on the Grand Prairie of Arkansas*, by B. S. Clayton, *Agricultural Experiment Station, College of Agriculture, University of Arkansas, Bulletin* No. **261**, May 1931

(7) *Prairie rice culture in the United States: United States Department of Agriculture, Farmers' Bulletin* **1092**, Nov. 1921, p. 5

(8) *Rice*, by J. Mitchell Jenkins, 1936 : The Louisiana State Department of Agriculture and Immigration

(9) *Varieties of rice for Texas : Texas Agricultural Experiment Station, Bulletin* No. **485** Nov. 1933

(10) *Experiment in rice production in South-western Louisiana : Department Bulletin* No. **1356**, *United States Department of Agriculture*

(11) *Civil Engineering :* American Society of Civil Engineers, July 1937, p. 502

(12) *Hydraulic Engineering, China*, Vol. **10**, No. 1. 1936

(13) *Monthly Journal of Reconstruction Bureau of Kiangsu Provincial Government, China*, Vol. **3**, No. 8, 1936

(14) *Rice experiment at Canton : Bulletin* No. **1**, *College of Agriculture, National Chunsan University, Canton, China*

(15) *Climatic factors of China*, by Coching Chu, *Journal of the Geographical Society of China*, Vol. **II**, No. 2

(16) *Hydraulic Engineering, China*, Vol. **13**, Nos. 1, 2, 3, 1937

(17) *Hydraulic Engineering, China*, Vol. **12**, No. 3, 1937

(18) *Grouping of soils on the basis of mechanical analysis*, by R. O. E. Davis and H. H. Bennett : *Department Circular* No. **419**, U. S. D. A.

(19) *Notes on soil mechanics and foundations*, by Fred L. Plummer, p. 32

(20) *Evaporation from the surface of water and river bed materials*, by R. B. Sleight : *Journal of Agricultural Research*, Vol. **10**, No. 5, p. 237, 1917

PLANT QUARANTINE NOTIFICATIONS

INDIA

Notification No. F. 43-32/20-A., dated January 16, 1941 of the Government of India in the Department of Education, Health and Lands

IN modification of this Department Notification No. F. 116/34-A., dated the 28th November 1935, it is notified for general information that the Government of Bombay have decided to levy a fee of Re. 1, in addition to incidental charges, to cover the cost of fumigation or disinfection, of each consignment of plants or fruits, intended for export to countries abroad, which is sent for inspection and certification to the Agricultural College, Poona.

Notification No. F. 43-15 (16)/40-A., dated February 4, 1941 of the Government of India in the Department of Education, Health and Lands

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F.-320/35-A., dated the 20th July 1936, namely :—

In the said Order—

(1) in sub-paragraph (1) of paragraph 5, after the words ' other than ', the words ' unmanufactured tobacco imported from Burma ,' shall be inserted: and

(2) in paragraph 8-B, after the words ' British India ', the words ' by sea ' shall be inserted.

Notification No. F. 15-2/41-A., dated February 12, 1941 of the Government of India in the Department of Education, Health and Lands

WITH reference to this Department notification No. F.-147/34-A., dated the 26th January 1935, it is notified for general information that the health certificate, required under Article I of the Decrees issued by the Governor General of Indo-China, dated the 8th March and 6th July 1933 relating to the importation of fruits into Indo-China, may be issued in the Province of Bombay by either the Plant Pathologist to the Government of Bombay or by the Professor of Entomology, Agricultural College, Poona.

Notification No. F. 15-9/41-A., dated March 6, 1941 of the Government of India in the Department of Education, Health and Lands

IN exercise of the powers conferred by sub-section (*1*) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A., dated the 20th July 1936, namely :—

In the First Schedule annexed to the said notification in columns 2 and 3—

(1) for the entry relating to ' Malay Peninsula ' the following entry shall be substituted, namely :—

Malay Peninsula . . .	The Department of Agriculture or/and Gardens, Straits Settlements, Federated Malay States and Unfederated Malay States.

(2) the entry relating to 'Straits Settlements' shall be omitted.

(3) against paragraph 7, after the entry relating to 'Burma', the following entry shall be inserted, namely.—

'Malay Peninsula . . .	Head of the Pathological Division of the Rubber Research Institute.'

(4) against paragraph 8-A, for the entry relating to 'Burma' the following entry shall be substituted, namely :—

'Burma	Mr. L. P. Khanna, M.Sc., Lecturer in Biology, University College, Rangoon.'

GIPD—S3—730 IC of AR—26-6-41—750.

ERRATA

INDIAN JOURNAL OF AGRICULTURAL SCIENCE, VOL. 10, PART V

Page 754, line 22,
Plate XXXIII, letterpress of fig. 2,
Page 756, lines 7 and 17 and Table II, col. 1, line 1,
Page 757, line 16 from bottom and Table III, col. 1, line 5,
} *for* ' Kurakkan ' *read* ' Kurkau '

Plate XXXIV, letterpress, *for* ' (var. colour)' *read* ' (var. Olour)'.

TABLE IX

*Particulars of experiments performed to transmit the disease from tobacco to tobacco**

Serial No. 1	Time of experiment and type of source of inoculation 2	Age of tobacco infected (weeks) 3	No. of plants infected 4	No. of white-flies used 5	Period of feeding (hours) 6	No. of plants which developed disease 7	Minimum No. of white-flies and minimum period of feeding resulting in successful transmission $\left(\frac{\text{No.}}{\text{Hrs.}}\right)$ 8	Incubation period of disease (days) 9	Percentage of successful transmission 10	Type of disease appearing and remarks 11
(*i*)	14-15 Sept. 1939 (*AX*)	11	12	2—7	7—24	1	$\frac{2}{16}$	23	8	*X*
(*ii*)	Do. . .	9	10	1—9	7½—24	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*iii*)	1-3 Nov. 1939 (*D*) .	11	9	5—16	15—21	4	$\frac{5}{15}$	67	44	3, *DX*; 1, *X*
(*iv*)	16-17 Nov. 1939 (*D*) .	9	10	7—14	21		$\frac{7}{21}$	18—24	90	2, *D*; 1, *DX*; 2, *C* & *D*; 4, *A* & *D*
(*v*)	8 Dec. 1939 (*A* & *D*) .	8	2	8—10	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vi*)	8 Dec. 1939 (*BX*) .	8	3	9—11	6½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
(*vii*)	4-5 Jan. 1940 (*A* & *D*)	7	11	1—14	17½	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*

* None of the controls of the various series developed leaf-curl disease.

successful and the minimum feeding period tested which resulted in the transmission of virus in the case of various food plants are given. The minimum and maximum incubation periods and the times of respective inoculations are also stated in the table. It will be observed that in the case of a large number of food plants, e.g. *Zinnia*, *Scoparia*, *Solanum*, ***Euphorbia***, *Vernonia*, *Launea*, *Sida*, only one specimen was tested, and it successfully transmitted the disease to tobacco. Similarly one specimen was enough to transmit the disease from tobacco back to zinnia. Thus it is evident that one white-fly is sufficient to transfer the leaf-curl virus to a healthy seedling. As regards the minimum feeding period necessary for successful transmission, one hour period was tested in the case of *Zinnia* and *Sida* and the disease was transmitted.

As regards the incubation period inside the inoculated plant, a perusal of Table X (columns 4 and 5) will show that the period was minimum if the inoculations were done either in July-November or in February-March. The incubation period was maximum generally in the case of inoculations which were done in December or January, though in a few cases of inoculations done in October and November the period was also maximum. Thus the experiments performed during 1938-40 confirm the conclusions arrived at in our previous paper that temperature plays an important part in the development of the disease and that low temperature suppresses the symptoms, as is the case with the ' yellow dwarf ' of potatoes [Goss and Peltier, 1925], ' curly top ' of sugar beat [Smith, 1933], tobacco mosaic [Grainger, 1936 ; Spencer, 1938], etc. Apart from air temperature affecting the plant directly, it is probable that the white-fly is most viruliferous when the temperature is moderate.

It was also observed that the feeding period remaining the same, the number of white-flies employed had no relation to the incubation period.

TRANSMISSION EXPERIMENTS WITH *BEMISIA GIFFARDI* KOTINSKY

In order to ascertain as to whether any other species of *Bemisia* besides *B. gossypiperda* is also capable of transmitting the virus or viruses of tobacco leaf-curl, some inoculation experiments with *B. giffardi*, which is also common at Pusa, have been performed during the last two tobacco seasons (1938-39 and 1939-40). The only food plant on which *B. giffardi* has been so far observed at Pusa is *Jasminum sambac*. Adult specimens (25 to 55 in number) were collected from this food plant and encased, like specimens of *B. gossypiperda*, in micro-cages on the diseased tobacco plants. They, however, did not seem to feed on tobacco at all. Then cellophane cages were used for providing more space for white-flies to move about freely. Even in such cages they were indifferent to tobacco plants and eventually they died. A large number of individuals of *B. giffardi* collected from diseased jasmine plants were similarly encased on healthy tobacco plants to see if they would feed on the latter and transfer the disease to them. They were found to live only for a few hours on diseased or healthy tobacco plants without feeding on them. It may be, therefore, concluded that *B. giffardi* is not a vector of the leaf-curl virus of tobacco, and that tobacco is not a food plant of this species.

TABLE X

Minimum number of white-flies tested and found successful and minimum feeding period tested which resulted in the transmission of virus from various food plants

Host 1	Minimum No. of white-flies tested and found successful and the period they fed on diseased source in the particular experiment 2	Minimum period tested for successful transmission (hrs) and No. of white flies employed in the particular experiment 3	Minimum incubation period (days) and the time of experiment when the period was such 4	Maximum incubation period and the time of experiment when the period was such 5	Remarks 6
Zinnia to tobacco . . .	1—4½ hrs. (Oct.) .	1—3 specimens (Nov.)	18—Nov. 1938 . .	38 hrs... ...Jan. 1939 72 hrs.......Oct. 1939	
Tobacco to *Zinnia* . . .	1—18 hrs . .	18—1-5 ,, ,,	11—Aug. 1939 . .	29 hrs...... Aug. 1939	Only one set of experiments performed (Aug. 1939)
Vernonia to *Zinnia* . . .	5—14 hrs . .	14—5-7 ,, ,,	21—Aug. 1939 . .	23 hrs.......Aug. 1939	
Scoparia to *Zinnia* . . .	1—22 hrs . .	22—1-5 ,, ,,	15—Aug. 1939 . .	34 hrs.......Aug. 1939	
Euphorbia to *Zinnia* . .	2—20 hrs . .	20—2-5 ,, ,,	27—Aug. 1939 . .	......	
Zinnia to *Zinnia* . . .	1—18 hrs . .	18—1-10 ,, ,,	11—Aug. 1939 . .	29 hrs.......Aug. 1939	
Solanum to tobacco . .	1—8 hrs (July and Nov.).	4½—7 specimens (Dec.)	11—July 1938 . .	48 hrs.......Dec. 1939	
Euphorbia to tobacco . .	1—23 hrs (July) .	6—2 specimens (Dec.)	10—July 1938 . .	64 hrs.......Oct. 1939	
Vernonia to tobacco . .	1—38 (Sept.) . .	6—9 specimens (Oct.)	14—July and Oct. 1938	50 hrs.......Jan. 1939	
Tomato to tobacco . . .	7—24 (Feb.) . .	6—12 specimens (Dec.)	20—Feb. 1939 . .	42 hrs.......Dec. 1939	
Launea to tobacco . . .	2—21 (July) . .	5½—6 specimens (Dec.)	9—July 1939 . .	57 hrs.......Dec. 1939	
Sida to tobacco . . .	1—17 (Oct.) . .	1—3 specimens (Nov.)	19—Sept. 1939 . .	78 hrs.......Dec. 1939	
Scoparia to tobacco . . .	2—24	7—16 . . .	15—Sept. 1939 . .	95 hrs.......Oct. 1939	
Tobacco to tobacco . . .	2—16 (Sept.) . .	15—5 . . .	18—Nov. 1939 . .	67 hrs.......Nov. 1939	

DISCUSSION AND CONCLUSIONS

From the foregoing account it will be evident that a large variety of cultivated plants and weeds are alternate hosts of tobacco leaf-curl, and that the white-fly, *B. gossypiperda*, can easily transmit the disease from a large number of them to tobacco. Besides sann-hemp and *Ageratum conyzoides*, which have already shown to be very important alternate hosts [Pruthi and Samuel, 1939], in the case of the following plants transmission experiments have generally given over 50 per cent positive results, and therefore they can be definitely considered to harbour leaf-curl virus or viruses : *Zinnia elegans, Solanum nigrum, Euphorbia hirta, Vernonia cinerea, Lycopersicum esculentum.* In addition to these, *Launea asplenifolia, Sida rhombifolia* and *Scoparia dulcis* also appear to be alternate hosts of the disease as the percentage of positive transmission from them was sometimes 40-45.

As regards the actual sources of leaf-curl infection to tobacco in the field, it does not necessarily follow that all the plants named above are sources of danger to this crop. To determine the real sources, one has to consider the time of the year when the above plants occur in the field and the time when they show the incidence of the disease, remembering that tobacco is most susceptible to infection from September up to the end of November [Pruthi and Samuel, 1937, 1939]. Though our experiments reported in the present paper show that tobacco can get infected during spring (February-March) also, if it is not more than about ten weeks old, it is only of academic interest as in actual practice the tobacco crop in North Bihar is generally harvested in January-February and, if it is still standing, only young leaves of the offshoots get diseased.

In Fig. 2, the seasonal histories of tobacco and the various alternate hosts of leaf-curl are diagrammatically shown. The diagram shows 11 concentric circles divided into 12 equal parts to represent the different months of the year, and each circle is designed to represent a particular host plant. Sunn-hemp, *Agertarum conyzoides* and *Zinnia elegans*, which are alternate hosts of tobacco leaf-curl, have been shown by us to have alternate hosts of their own disease. For example, in the case of sunn-hemp, *Ageratum conyzoides* and *Euphorbia hirta* are such hosts and diseased sunn-hemp is also a definite source of infection for healthy sun-hemp. Such alternate host plants are, therefore, shown in the background of sunn-hemp. In the same way, tobacco, *Vernonia, Scoparia, Euphorbia* and *Zinnia* are all shown in the circle for *Zinnia*, showing that infection from them can go to healthy *Zinnia*. Similarly *Ageratum*, besides having diseased *Ageratum* as a source of infection, has sunn-hemp and tobacco as alternate hosts.

In the case of tobacco, the large number of alternate host plants, which have been enumerated already, are shown in the circle for this crop. A glance at the calendar shows that during the four months of February-May, practically no alternate host plant exists in the field, and there is no tobacco crop in the field or nurseries between June and the middle of August. Therefore, the alternate hosts actually dangerous to tobacco are those which show the disease in August-November.

The garden zinnia, in the case of which the white-fly has been shown to transmit the disease very readily, shows leaf-curl in the field during August-October, and thus diseased zinnia is an important source of danger to tobacco

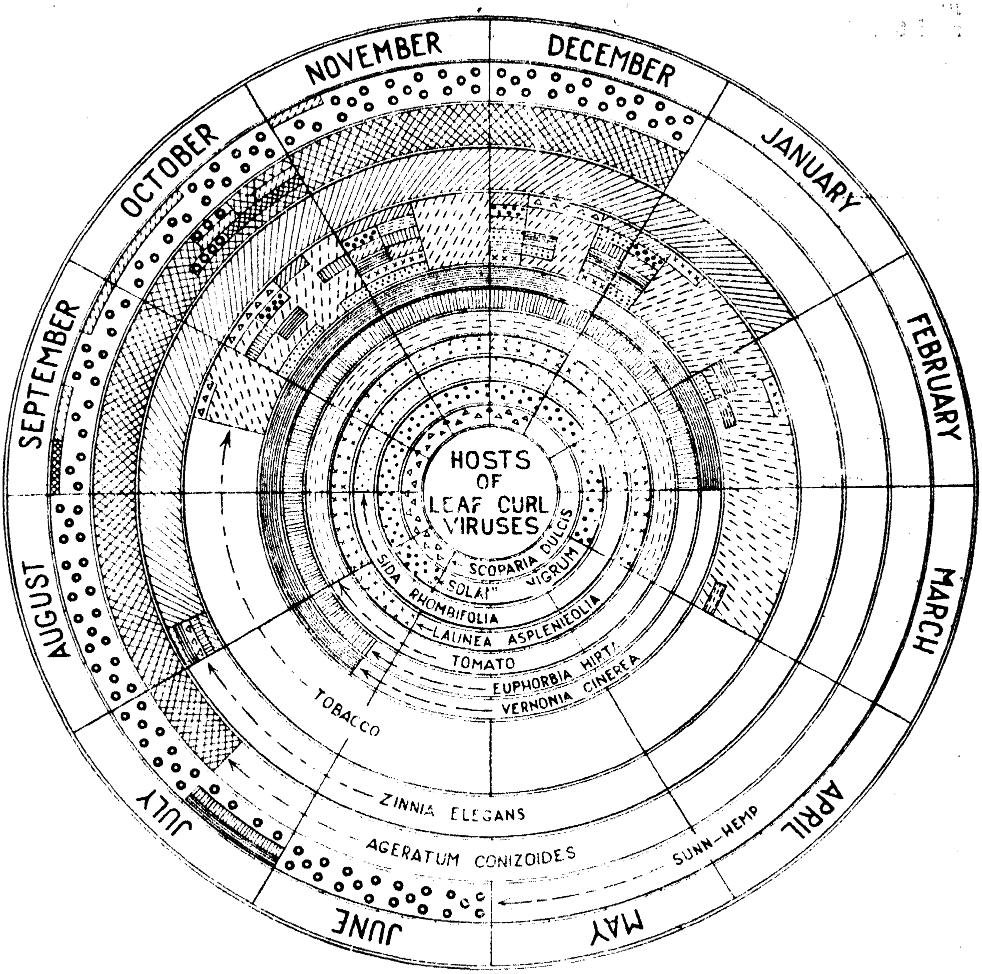

FIG. 2. Seasonal histories of tobacco and various alternate hosts of leaf-curl

crop, like sunn-hemp and *Ageratum* which too have been shown such as stated above. Similarly, *Vernonia*, *Solanum nigrum* and *Euphorbia* are sources of danger during October and November and tomato and *Launea* in November and December.

As a result of our previous investigations [Pruthi and Samuel, 1937; 1939], we showed that tobacco suffers from several types of leaf-curl, designated *A*, *B*, *C*, *D* and *X*, of which *A* and *D* are also found in sunn-hemp and *Ageratum* from which they can be easily transmitted to tobacco by the white-fly. The additional plants which have been shown to be alternate hosts of tobacco leaf-curl in the present paper have in some cases given rise to different types of the disease in tobacco. The types which are caused when the various plants are used as sources of infection are stated in column 11 of Tables I-IX and the information is summarized below :—

Source	Type of disease developed on tobacco
Zinnia elegans	*C*, *D* and *X*
Solanum nigrum	*B*, *C*, *D*, all the three often mixed with *X*
Euphorbia hirta	*B*, in a few cases *C*, both often mixed with *X*
Vernonia cinerea	*A* and *C*, both mixed with *X*
Lycopersicum esculentum	*A*
Launea asvlenifolia	*X*, sometimes *DX* also
Sida rhombifolia	*C*, sometimes *A* also
Scoparia dulcis	*X*

Thus it will be observed that we have discovered at least one alternate host for each type of leaf-curl disease of tobacco. Probably there are several hosts for each type.

In our previous papers [Pruthi and Samuel, 1937 ; 1939], we showed that the tobacco crop is most susceptible to infection from September up to the middle of November. In the investigations reported in this paper, the maximum percentage of successful transmission with various alternate plants (see column 10 of tables) was also obtained during the months named above. Transmission experiments performed during July and August and again in February with 8-10 weeks old tobacco seedlings also gave a very high percentage of successful results, but this is of not much practical importance because, as already stated, tobacco is not in the field till September, and by February it gets harvested or if standing its young offshoots only get the infection.

From the foregoing it will be observed that to attempt to control the leaf-curl disease of tobacco by the eradication of its various alternate host plants is a very laborious if not impracticable work. The alternative methods of control are to evolve resistant varieties or to check the white-fly vector by means of dusting and spraying at suitable times of the season. We have done some work on the latter method and the results are very encouraging. During the next season we propose to try this method on a field scale and will report the results in due course.

It is noteworthy that with another species of white-fly, viz. *B. giffardi* which is also common at Pusa, no successful transmission was obtained in the case of any plant. In fact it did not feed on tobacco at all.

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REFERENCES

Goss, R. W. and Peltier, G. L. (1925). *Bull. Nebr. Agric. Expt. Sta.* **29**

Grainger, J. (1936). *Nature* **137** (3453), 31-2

Johnson, J. (1927). *Res. Bull. Wisc. Univ. Agric. Expt. Sta.* **76**, 1—16

Mathur, R. N. (1933). *Ind. J. Agric. Sci.* **3**, 89-96

McClean, A. P. D. (1931). *Sci. Bull. Pretoria* **100**, 1—36

Pruthi, H. S. and Samuel, C. K. (1937). *Ind. J. Agric. Sci.* **7**, 659—70

———————————— (1939). *Ind. J. Agric. Sci.* **9**, 223—75

Smith, K. M. (1933). *Recent advances in the study of plant viruses*: London

Spencer, E. L. (1938). *Phytopathology* **28**, 147-50

Storey, H. H. (1928). *Ann. Appl. Biol.* **15**, 1-25

———— (1935). *E. Afr. Agric. J.* **1**, 148-53

Thung, T. H. (1934). *Meded. Proefst. Vorstenlandsche Tabak*, No. **78**, 1—18

STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB

IX. VARIETAL SUSCEPTIBILITY TO THE DISEASE

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THE most destructive disease of cotton in the irrigated parts of this province is cotton root-rot. The disease becomes active during the months of June and July soon after the first irrigation when the plants are about four to six weeks old, and usually results in extremely heavy losses to the crop.

It has already been reported that cotton root-rot is caused by *Rhizoctonia solani* and *R. bataticola.** The disease flourishes in the presence of excessive moisture and high summer temperatures (1937, 1939).

During the investigation of control measures for the disease a thorough search has been made for a variety which might be immune or resistant to the disease. In this connection almost all the important Indian types and a very large number of foreign types obtained from different cotton-growing countries of the world have been tested in the past seven years for their resistance to root-rot. The results of these trials are recorded in this paper.

METHOD

The susceptibility of various varieties and selections was tested in highly and uniformly infected plots which had been under observation for several years. The tests were conducted at Lyallpur where climatic and soil factors are very favourable for the progress of the disease. Prior to the field selection of varieties the plot of land was sown with local cottons which are known to be highly susceptible to the disease for two or three seasons to ensure uniform spread of the disease in the entire plot, as this is necessary to obtain reliable and comparable data. The varieties to be tested were sown at the optimum time for the occurrence of the disease, i.e. during the month of May.

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* *Rhizoctonia bataticola* = C Strain of Haigh = *Macrophomina phaseoli*

EXPERIMENTAL RESULTS

VARIETAL SUSCEPTIBILITY

(a) *Susceptibility of Punjab cottons to root-rot*

To begin with only important Punjab varieties were tested for their susceptibility to root-rot. The degree of their susceptibility was determined by sowing them in a heavily infected field. The various varieties were sown in such a way that they were all uniformly distributed over the whole plot. The death rate counts were taken at weekly intervals throughout the cotton season. The dead plants were pulled out and examined for root-rot symptoms and, if there was any doubt as to the cause of death in any plant, isolation of the organism was resorted to. The actual position of the plants which had been killed was indicated in the field by cotton sticks which had been previously dipped in coal tar to safeguard against the attack of white ants. This method facilitated checking of the counts at different periods during the root-rot season which extends from June to October.

The susceptibility tests were conducted in two different plots. In one plot four varieties of *desi* (*G. indicum*) and three of American (*G. hirsutum*) and in the second plot six of American and one of *desi* cottons were tested. The results of these experiments are summed up in Table I. As the two experiments were conducted in different fields, the results of the two experiments are not comparable with each other.

TABLE I

Susceptibility of some Punjab cottons to root-rot

Plot I					Plot II				
Variety	Species	Total No. of plants	Plants killed	Per cent root-rot mortality	Variety	Species	Total No. of plants	Plants killed	Per cent root-rot mortality
4 F	*G. hirsutum*	289	114	39·44	LSS	*G. hirsutum*	557	237	42·55
15	*G. indicum*	298	146	48·99	43 F	Do.	622	245	39·99
289 F	*G. hirsutum*	276	136	48·74	45 F	Do.	490	189	38·57
10	*G. neglectum*	251	132	52·54	Jubilee cotton	(Million Dollar × Mollisoni 15)	594	184	30·89
50	*G. indicum*	247	138	55·87	58 F	*G. hirsutum*	640	272	42·50
12	*G. sanguineum*	248	141	56·85	15	*G. indicum*	727	252	34·66
43 F	*G. hirsutum*	267	158	59·20	4 F	*G. hirsutum*	611	229	37·48

The data given in Table I show that all the varieties tested are highly susceptible to the disease. In another season seven more Punjab varieties, i.e. Mollisoni 39, 41, 46 F, 47 F, 289 F, 83 AF and 38 F were tested, the first two varieties being *desi* and the remaining five being American. The mortality records were taken throughout the season and it was found that all the varieties succumbed to the disease to more or less the same degree, and results quite similar to the above were obtained.

Such tests with the Punjab varieties were repeated during a number of seasons and no variety showed any appreciable resistance to the disease. In certain seasons the average percentage of mortality in the cottons tested was extremely high being 60-80 per cent.

(b) Susceptibility of cottons from other Indian provinces

All the Punjab cottons having been found highly susceptible to root-rot disease, a number of important types from other provinces in India were obtained in order to find out if any of those varieties was resistant to the disease. The first lot of these varieties was tested in 1937 in a heavily infected plot. The middle of May is the optimum for the occurrence of the disease. The sowings were done on 22 May. Eight varieties were tested and four repeats of each variety were kept. Two Punjab varieties were sown as controls for comparative purposes. The results of these tests are given in Table II.

TABLE II

Susceptibility of cottons from other Indian provinces to root-rot

Variety	Species	Source	Total plants	Plants killed	Average per cent root-rot mortality	Root-rot mortality range
V 438	*G. arboreum*	Central Provinces	157	124	84·8	68·6—90·7
Bani 306	Do.	Do.	153	129	84·7	73·7—97·1
V 434	Do.	Do.	164	134	81·7	72·7—95·5
E B 31	Do.	Do.	119	99	67·3	39·1—90·0
Late verum	Do.	Do.	166	140	84·5	80·0—95·0
C 520	Do.	United Provinces	144	105	72·2	62·5—81·1
C 402	Do.	Do.	110	76	67·0	84·4—88·5
Cambodia cotton	*G. hirsutum*	Bombay	124	88	70·6	57·7—83·3
4 F	Do.	Punjab (control)	191	141	73·7	66·0—82·0
43 F	Do.	Do.	158	122	77·0	70·6—82·1

The results given above show that all the eight varieties tested are susceptible almost to the same degree as the Punjab cottons.

Some more samples of cotton seeds were obtained from other cotton-growing parts in India during 1938 and 1939 and subjected to field trials at Lyallpur. Results similar to the above were obtained, showing thereby that all the Indian varieties tested are highly susceptible to root-rot. The results of such tests, conducted in 1939, showing percentage of root-rot mortality are summed up in Table III.

TABLE III

Susceptibility of Indian cottons to root-rot in the Punjab

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	Gaorani 4B-5	*G. arboreum*	Nizam's Dominions (Hyderabad)	94·1	100·0
2	Gaorani 6		Do.	98·3	100·0
3	Gaorani 12F		Do.	97·2	100·0
4	Gaorani 113		Do.	72·5	100·0
5	Cutchica 9		Do.	84·9	100·0
6	Parbhani-American	*G. hirsutum*	Do.	65·7	79·4
7	Perso-American		Cawnpore (U. P.)	48·9	69·4
8	Rozi	*G. arboreum*	Baroda State	55·7	77·7
9	Karkhadi (Bulk general) (unselfed)		Do.	71·0	81·8
10	Karkhadi Family No. 12		Do.	65·1	71·4
11	Karkhadi Family No. 15		Do.	95·2	100·0
12	Karkhadi Family No. 18		Do.	77·6	92·8
13	Karkhadi Family No. 26		Do.	71·2	78·6
14	Strain Co 2	*G. hirsutum*	Coimbatore (Madras)	67·5	83·3
15	Strain 920		Do.	62·0	75·0
16	Kampala bulk (Naked)		Do.	54·5	69·2
17	Jinja bulk (Naked)		Do.	38·5	58·3
18	× 3915 Q, Cambodia × Uganda		Do.	77·9	100·0
19	× 4463 B2, Cambodia × Uganda		Do.	54·4	72·7
20	× 4383 B, Uganda × Cambodia		Do.	54·6	100·0
21	Bourbon (*G. religiosum*)		Do.	39·2	46·1
22	Nadam bulk	*G. arboreum*	Coimbatore (Madras)	92·8	100·0
23	*Neglectum roseum* bulk		Do.	81·6	100·0
24	No. 4714 Cocanadas × (N 14 × *Cernuum*)		Do.	91·5	100·0
25	No. L3 4/4 Re-selection from 4714		Do.	87·8	100·0
26	No. c 6/3 Natural cross in N × *Cernuum*		Do.	80·7	100·0
27	Karunganni K I		Koilpatti (Madras)	95·2	100·0
28	Nandyal 14		Nandyal (Madras)	95·8	100·0
29	Cocanadas 171		Guntur (Madras)	100·0	100·0
30	83 A F (*G. hirsutum*)		Punjab	68·3	80·7
31	Uppam 2919	*G. herbaceum*	Hagari	90·4	100·0
32	Western H I		Do.	94·4	100·0
33	Strain 19	*G. herbaceum* × *G. arboreum*	Mysore State	86·3	100·0
34	H 190		Do.	91·7	93·3
35	Nadam-like		Do.	81·9	90·9
36	*Cernuum* Nadam 86 (*G. cernuum* × *G. obtusifolium*)		Do.	78·8	91·1
37	M A$_2$ (Upland cotton × Peruvian tree cotton)		Do.	82·0	96·6
38	Mollisoni 39 (*G. indicum*)		Punjab	74·5	100·0

(c) *Susceptibility of foreign cottons*

As there appeared to be little chance of picking up a resistant or a partially resistant type from Indian cottons, six samples of cotton seed were obtained from America in 1937 and a preliminary test conducted in order to determine their susceptibility to root-rot. The mortality percentage in the six American samples varied from 19 to 38 as against 74 per cent in the Punjab American cotton (43 F). The number of plants tested for each variety was, however, extremely small being 25-44. To confirm the above findings, these samples were again tested in the field in 1938. This time about 100 plants of each were kept. All the samples were found to be severely attacked and showed a maximum mortality of 52-93 per cent, showing thereby that these foreign types had somehow escaped a severe attack in the first season. All the same it was considered worth while to test a wide range of exotic cottons, and seed of a large number of foreign varieties was imported and trials conducted in 1938. As the number of varieties was fairly large, these had to be tested in two separate plots. Seventeen samples with Punjab 4 F control were sown in one plot and the remaining 95 with two Punjab cottons as controls were sown in another plot. Three repeats comprising 100-120 plants of each of the samples were kept and mortality counts made at weekly intervals throughout the season. The data of these tests conducted in 1938 in two different plots are recorded in Tables IV and V.

The results recorded show that all the samples tested suffered a heavy loss due to root-rot and none of the types showed marked resistance to the disease. Most of the types opened badly and produced immature seed which failed to germinate; others produced seed in which the percentage of germination as tested in the laboratory was extremely low, i.e. below 11 per cent.

All the same, certain varieties which showed a maximum mortality up to 40 per cent and produced some viable seed were subjected to a further test. The selfed seed of individual plants was sown in separate rows in 1939 in a heavily and uniformly infected plot. The progeny of all the plants of various varieties was severely attacked by root-rot, mortality being 53-77 per cent, showing thereby that the material was highly susceptible and could be safely discarded.

Similar tests with exotic cottons were carried out in 1939 with the fresh material obtained from various cotton-growing countries and in addition some of the last year's samples were also included in these trials. The data are tabulated in Table VI.

Most of the varieties were severely attacked by root-rot, but the others were less severely attacked and the range of maximum mortality varied from 26 to 42 per cent. Some of these had shown extremely high mortality in 1938 and were therefore discarded, whereas the remaining nine were selected and tried in 1940, but all were found to be susceptible.

RESISTANCE OF INDIVIDUAL PLANTS TO THE DISEASE

The disease invariably appears in patches and a few healthy looking plants may be seen scattered here and there in the diseased patch. These plants grow to their full size and yield almost as well as those plants which

TABLE IV

Susceptibility of some foreign cottons to root-rot (1938)

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	Z 14 . . .	*G. hirsutum.*	Zomba, Nyasaland .	33·8	57·9
2	C 28 . . .		Do. .	42·2	66·6
3	N 3 . . .		Do. .	35·5	46·4
4	N 10 . . .		Do. .	41·0	55·2
5	U 4.4.2. . .		Do. .	59·5	73·3
6	Lonestar Lot 33		Brisbane, Queensland	35·9	53·3
7	Lonestar Lot 34		Do. .	32·0	44·4
8	Miller Lot 42		Do. .	31·6	61·1
9	Cliett . .		Do. .	29·9	40·0
10	Mebane . .		Do. .	55·9	67·9
11	New Boykin .		Do. .	55·9	58·3
12	Stoneville . .		Washington . .	33·8	48·3
13	Acala Shafter .		Do. . .	37·8	50·0
14	Coker, Cleveland		Do. . .	33·1	37·0
15	Coker's Farm, Relief No. St. 3		Do. . .	36·6	56·6
16	D. & P. L-11 .		Do. . .	41·1	46·6
17	Mebane, Triumph		Do. . .	40·5	51·7
18	4F . .		Punjab (control) .	59·7	72·4

TABLE V

Susceptibility of foreign cottons to root-rot (1938)

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed	Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	U/4 Bulk	*G. hirsutum*	Morogoro, Tanganyika Territory	29·2	43·5	23	920	*G. hirsutum*	Barberton, Transvaal	32·1	42·1
2	U/4/4		Do.	41·5	65·0	24	921		Do.	42·8	64·7
3	998		Do.	43·4	77·0	25	052		Do.	27·6	43·2
4	7 L 6		Gatooma, South Rodesia	25·1	46·1	26	95		Do.	30·3	33·3
5	7 L 7		Do.	27·4	42·1	27	5149		Do.	0·5	40·0
6	7 L 10		Do.	35·7	52·6	28	998 R		Do.	25·0	35·0
7	7 L 24		Do.	46·6	60·0	29	B × 172		Sigatoka, Ginnery	58·2	64·3
8	G, 5·136		Do.	54·7	61·6	30	Allen		Ibadan, Nigeria	53·3	77·5
9	Giza 12	*G. peruvianum*	Giza, Egypt	44·4	56·4	31	514 D		Sudan	58·1	75·0
10	Giza 19		Do.	64·3	78·9	32	XA 129		Do.	65·8	79·5
11	Giza 26		Do.	65·2	89·2	33	XA 1129		Do.	61·7	72·5
12	Giza 7		Do.	51·6	78·4	34	511 C		Do.	54·8	76·3
13	Sakha 4		Do.	62·0	73·0	35	Gadag No. 1		Do.	82·0	89·2
14	Sakha 7		Do.	67·1	75·7	36	39 Mollisoni	(*G. indicum*)	Punjab (control)	83·2	89·5
15	365	*G. hirsutum*	Morogoro, Tanganyika Territory	45·6	71·8	37	83 A F	*G. hirsutum*	Do.	68·1	89·2
16	530		Do.	52·1	76·3	38	Missdel 7		Greenville, Mississippi	65·0	87·5
17	244		Do.	40·3	57·5	39	Paymaster		Texas	41·2	48·7
18	No. 553		Do.	65·[illegible]	75·0	40	Rhyne's Cook		Alabama	49·5	62·8
19	Local		Do.	54·2	72·5	41	Missdel 1-0539		Greenville, Miss.	46·5	54·5
20	B P 52		Uganda, Africa	49·2	57·5	42	Mebane		Lockhart, Texas	57·2	92·5
21	B P 79		Do.	38·3	57·5	43	Chapman, Ranch, Mebane		Texas	44·4	37·5
22	U B 24/4		Do.	37·0	42·5	44	Rowden 2088		Scott, Arkansas	37·9	40·0

45	**Harper**	*G. hirsutum*	**Martindale, Texas**	47·7	55·3	71	Caddo	*G. hirsutum*	**Waco, Texas**	44·2	53·8
46	**Cliett**		**San Marcos, Texas**	40·0	50·0	72	Ferguson 406		Howe, Texas	38·1	48·6
47	**Mebane 140**		Chillicothe, Texas	29·1	40·0	73	Sunshine		Mekinney, Texas	47·9	60·0
48	**Mebane 804-50**		**Beeville, Texas**	49·5	55·0	74	Kasch		San Marcos, Texas	47·7	52·9
49	**Mebane 141**		**Chillicothe, Texas**	66·6	72·4	75	Bryant Mebane		Corsicana, Texas	48·9	65·0
50	**Jennings**		**Plain View, Texas**	43·9	52·8	76	Watson		Garland, Texas	21·7	31·0
51	**Cluster**		**Austwell, Texas**	59·2	79·5	77	Mebane		Lockhart, Texas	53·5	59·3
52	**Bagley**		Martindale, Texas	58·7	65·0	78	Lonestar		Tivoli, Texas	40·7	42·5
53	**Missdel, 4-91168**		Greenville, Miss.	44·9	61·5	79	Qualla		San Marcos, Texas	44·3	51·3
54	Delfos 719		Stoneville, Miss.	47·0	57·5	80	D & P L 11 A		Scott, Miss.	46·0	55·5
55	Delfos 513 B		Do.	28·4	40·0	81	Roldo Rowden		Scott, Arkansas	45·5	52·8
56	Stoneville 2 B		Do.	36·0	53·8	82	Paris Bigboll		Paris, Texas	41·2	56·4
57	Stoneville 4 A		Do.	45·1	61·9	83	Bennett's		Bryan, Texas	45·7	70·0
58	Stoneville 5 A		Do.	47·1	76·5	84	Acala, N 28-5		U. S. Field Station, State, College, N. M.	36·8	45·5
59	Missdel 6		Greenville, Miss.	47·0	71·8	85	Lankart		Waco, Texas	47·5	57·5
60	Aldridge		Planc, Texas	42·8	51·4	86	Startex		College, Station, Texas	48·2	70·2
61	Texas, Special		Itasca, Texas	52·7	65·0	87	Wild's Semiwilt resistant strain 2		Hartsville, S. C.	51·7	70·0
62	Wacona		Waco, Texas	54·3	67·6	88	Mebane		Troy, Texas	52·7	54·5
63	New Boykin		Howe, Texas	50·8	62·5	89	Lenty Acala		Austwell, Texas	50·6	67·6
64	Northern Star		Waco, Texas	34·9	38·9	90	Worley, Boykin		Rockdala, Texas	63·8	71·0
65	Webb's Purple		Union City, Okla.	35·8	50·0	91	Union		San Marcos, Texas	43·5	47·1
66	Hurley, Special		Cooper, Texas	49·9	52·5	92	Olander, Mebane		Hutto, Texas	58·2	75·0
67	Arkansas 17		Marianna, Ark.	49·5	53·8	93	Lonestar		Waco, Texas	44·4	51·4
68	Half & Half		B F Summerour Seed Co ; Narcross G A	49·1	55·0	94	Texas Mammoth		Knapp, Texas	43·2	54·1
69	Oklahoma Triumph		Stillwater, Okla.	49·1	62·5	95	Russell		Annona, Texas	37·2	61·5
70	Rog·ers, Acala		Navasota, Texas	37·2	42·5						

TABLE VI

Susceptibility of exotic cottons to root-rot (1939)

Serial No.	Variety or strain	Species	Source	Average per cent mortality	Maximum per cent mortality observed
1	Sea Island . .	(*G. barbadense*)	Cotton Suva (Fiji) .	41·9	60·0
2	Mebane . .	*G. hirsutum*	Brisbane . .	35·2	38·4*
3	Indo Acala .		Do. . .	21·8	50·0
4	Half & Half .		Do. . .	21·7	24·3*
5	Cliett . .		Do. . .	34·2	45·4
6	Ferguson . .		Do. . .	23·3	34·3
7	New Boykin .		Do. . .	32·9	37·5
8	Lonestar (L S 31-5-1-1-2-0)		Do. . .	39·3	42·1
9	Lonestar progeny (L S 30-2-4-3-0-1-0)		Do. . .	29·0	37·5
10	Lonestar progeny (L S 31-5-0-0-1-0)		Do. . .	34·1	41·6
11	Miller 42 . .		Do. . .	24·2	30·0*
12	Miller 41 . .		Do. . .	23·5	32·4†
13	Mesowhite . .		Cyprus (Nicosia) .	43·3	70·0
14	Coker 100 . .		Do. .	48·8	71·4
15	Clevewilt 5 .		Do. .	36·5	62·5
16	Titsiros . .	(*G. barbadense*)	Do. .	50·0	75·0
17	Triumph . .	*G. hirsutum*	Do. .	47·1	68·5
18	998 . . .		Nairobi (Kenya) .	34·6	42·8
19	9243 . . .		Do. .	23·8	27·5†
20	U/4 . . .		Do. .	26·2	27·2*
21	Rhyne's Clevewilt	*G. hirsutum*	Arkansas . .	30·8	32·2†
22	Clevewilt 6 .		Do. . .	33·7	42·8
23	Dixtri . .		Do. . .	26·6	33·3†
24	Coker Clevewilt strain 4		Do. . .	51·4	57·8
25	Dixit . .		Do. . .	50·3	63·6
26	C-28 . . .		Salima, Nyasaland .	20·4	30·5*
27	Z-14 . . .		Do. .	25·6	27·2*
28	N-10 . . .		Do. .	25·2	26·6*
29	U/4/4/2 . .		Tanganyika . .	33·1	42·4†
30	Local . .		Do. . .	19·7	22·5*
31	9264 . . .		Barberton, Transvaal	28·2	47·2
32	5143 . . .		Do. .	25·5	36·3†
33	920 . . .		Do. .	17·8	22·5*
34	Bancroft . .		Do. .	33·2	44·0
35	Delta & Pineland-12		Texas, U. S. A. .	30·3	53·3
36	Rowden 2088 .		Do. . .	31·2	36·3†
37	Delfos 130 . .		Do. . .	17·9	26·0†
38	Chinese Million-Dollar (Yellow Flower)	(*G. arboreum*)	Punjab . . .	57·7	78·9

39	Russian 2284	*G. hirsutum*	Coimbatore	47·8	54·5
40	Durango		Do.	52·9	61·5
41	Lonestar		Do.	43·9	58·8
42	Acala Ardmone		Do.	53·0	81·8
43	Hartsville		Do.	47·9	100·0
44	Western Wonder		Do.	46·3	83·3
45	Uganda Z 1/9		Do.	53·4	76·9
46	Uganda A 12		Do.	45·8	57·1
47	Quenbradinho (South America)	*G. barbadense*	Do.	56·9	80·0
48	Verdao (South America)		Do.	87·0	100·0
49	Giza 12 (*G. peruvianum*)		Do.	59·7	66·6
50	Sakel (Egyptian)	*G. barbadense*	Do.	80·5	100·0
51	Ashmoni (Egyptian)		Do.	70·0	75·0
52	Hopi-3 (Washington)	*G. religiosum*	Do.	80·8	87·4
53	Moco (South America)		Do.	84·5	91·6

54	Ishan-A (*G. barbadense*)		Ibadan (Nigeria)	73·8	100·0
55	Sokoto (*G. religiosum*)		Do.	94·5	97·5
56	Bauchi (*G. barbadense*)		Do.	78·0	88·0
57	Washington (Delfos 719)	*G. hirsutum*	Washington	32·5	50·0
58	Coker Clevewilt Str. 7		Do	35·5	50·0
59	Coker Farm Relief Str. 5		Do.	28·8	35·4†
60	Stoneville 2B		Do.	31·6	50·0
61	Delta pine A (D & Pl 11 A)		Do.	30·3	42·4
62	Acala (Shafter)		Do.	25·8	34·6*
63	Coker 100 Strain 2		Do.	36·1	50·0
64	Acala (Roger's)		Do.	22·8	33·3*
65	Coker wild's Strain 9		Do.	31·8	43·4
66	Mollisoni 39 (*G. indicum*)		Punjab	74·5	100·0

* High mortality in 1938

† Selected for further trials

are found growing in a disease-free area. Sometimes when two plants are growing at the same spot only one of them might succumb to root-rot, whereas the other appears to be healthy and seems to flourish like normal plants in disease-free fields throughout the season.

In order to find out whether these plants which escaped root-rot in diseased patches or those whose companion plant had died of root-rot attack are comparatively resistant to root-rot, experiments were conducted by selfing the flowers of such plants and testing the seed in the following season in a heavily infected plot. In this connection selection of plants was made as follows :—

(*i*) *Plants that escaped mortality in a heavily diseased plot*

Such selections which were made in the Farm area were selfed, whereas the selections made in zemindar's fields were not selfed. The selections were continued to be made from 1934 to 1939 and tested from year to year. In several cases such tests were conducted up to the third generation, but none of these selections gave indication of resistance to the disease.

Selections were also made from some of the foreign varieties and their selfed seed tested for resistance to root-rot. Progenies of all such selections were found to be highly susceptible.

(*ii*) *Plants whose companion plant had died of root-rot*

In a field 100 ft. × 212 ft. severely affected with root-rot *desi* cotton (Mollisoni 15) was sown in rows 3 ft. apart in 34 lines. About four cotton seeds were dibbled at a distance of every 2 ft. along the line. After germination had taken place two plants were kept in each hole in all the even lines, whereas single plants were maintained in a spot in all the odd lines so that single plant lines and double plant lines alternated throughout the plot.

Mortality counts were taken at weekly intervals throughout the season. The plants whose companion plant (growing in the same spot) had died of root-rot in the even lines were selected and their selfed seed tested under heavy conditions of infection in the field in the following season, but no indication whatsoever of resistance to the disease was obtained.

(*iii*) *Plants which wilt and then recover*

It has been observed that a plant here and there may wilt due to root-rot and then recover during irrigation, cool nights or wet weather. Though such recoveries are very rare, yet it was considered worth while to investigate whether progenies of such recovered plants showed any resistance to the disease. Selfed seed of a number of recovered plants was tested as usual in the following season along with controls and it was observed that progenies of all such selections suffered as heavy a loss due to root-rot as the controls.

(*iv*) *Plants with heavily and partially attacked roots*

Healthy looking plants of both *desi* and American varieties were selected from diseased fields and their seed selfed. The roots of these plants were examined after the crop was over and found to be heavily attacked, partially attacked and almost healthy. In the following season the selfed seed of these three lots was tested for resistance to root-rot separately and a single line was sown with the seed obtained from each plant. The trials were controlled by sowing lines of 4 F (*G. hirsutum*) and Mollisoni 15 (*G. indicum*). No indication of any appreciable resistance of the progeny to the disease was obtained.

(*v*) *Selections from mixed cottons*

As no evidence of resistance of any pure type to the disease was forthcoming, it was considered that there might be some scope for picking up a resistant type from the fields of mixed and unselected varieties of cotton. An attempt was made along these lines and seed from the mixed population of those farmers' crop who had not taken up pure strains of cottons was collected. Seed of both mixed *desi* and American cottons was obtained from different zemindars in the province including certain submontanous tracts where root-rot is practically absent. The samples were tested in a heavily infected plot and the mortality records taken throughout the season. The extent of attack in these samples was as great as in the pure type controls.

There is enough experimental evidence to show that the material so far tested is highly susceptible to the disease even under infection conditions present in the field which are by no means extremely severe. It was therefore not considered worth while to subject the material to further tests under controlled optimum conditions of infection.

SUMMARY

1. A very large number of varieties of cottons, both indigenous and exotics, have been tested with a view to finding a type resistant to root-rot disease in the Punjab. None of the varieties tested has shown any appreciable resistance to the disease.

2. Selfed seeds of apparently healthy plants in diseased plots did not yield resistant plants.

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REFERENCES

Vasudeva, R. Sahai (1937). *Ind. J. Agric. Sci.* **7**, 575-87

Vasudeva, R. Sahai and Mohd. Ashraf (1939). *Ind. J. Agric. Sci.* **9**, 595-608

STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB

X. EFFECT OF CERTAIN FUNGI ON THE GROWTH OF ROOT-ROT FUNGI

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(With Plates XIX and XX and two text-figures)

In a preceding number of this series [Vasudeva, 1936] it was shown that two *Rhizoctonia* species and a number of other fungi appeared frequently when isolations were made from diseased cotton roots. It was also indicated that the parasitic activity of *Rhizoctonia solani* is enhanced when it acts in combination with certain other fungi.

Experiments have now been conducted to find out whether there existed any conditions in which the growth of the parasitic fungi, *R. solani* and *R. bataticola*, could be reduced. Certain conditions under which it occurs have been investigated and are described in this paper.

Experimental

A. Fungi and media used

The following fungi were used during the course of this investigation.

Fungus	Source
Rhizoctonia solani Kuhn	Isolated from diseased cotton roots
Rhizoctonia bataticola (Taub.) Butler	Isolated from diseased cotton roots
Trichoderma lignorum (Tode) Harz.	Centraalbureau Voor Schimmelcultures, Baarn, Holland
Aspergillus niger Van Tieghem	Centraalbureau Voor Schimmelcultures, Baarn, Holland

Media employed

1. Richards' agar
2. Cotton-root synthetic agar [Vasudeva, 1936]
3. Soil extract agar

Soil	100 gm.
Agar	20 gm.
Distilled water	1,000 c. c.

4. Soil-farmyard manure extract, agar

Soil	50 gm.
Farmyard manure	50 gm.
Agar	20 gm.
Distilled water	1,000 c. c.

5. Glucose-peptone agar

Glucose	10 gm.
Peptone	2 gm.
KH_2PO_4	1 gm.
$MgSO_4$	0·5 gm.
Agar	15 gm.
Distilled water	1,000 c. c.

To start with, the purity of the fungi was ensured by taking a single hyphal tip.

B. Effect of mixture of organisms on growth

This effect was studied in thickly poured petri dishes containing about 50 c. c. of the medium. Altogether four media were used, i.e. cotton-root synthetic agar, Richards' agar, soil extract agar and soil-farmyard manure extract agar.

The general plan of the experiment was to place almost uniform inocula in the following manner in the centre of each plate and measure the rate of growth from day to day.

1. *R. solani* alone
2. *R. bataticola* alone
3. *Trichoderma lignorum* alone
4. *R. solani* and *Trichoderma* mixed
5. *R. bataticola* and *Trichoderma* mixed.

In the presence of *T. lignorum* in the mixed inocula the growth of *R. solani* and *R. bataticola* is appreciably reduced on all the media tested. In such cases the colonies which grew out consisted mainly of *T. lignorum*.

Effect of mixed inocula was also studied by inoculating the petri dishes containing Richards' agar at the centre with a suspension of hyphae of *R. solani* and *R. bataticola*. The inoculum was encircled at a distance of about 1 cm. by a suspension of spores of *T. lignorum* . It was observed that the small colony of *R. solani* and *R. bataticola* was completely encircled by *T. lignorum* and it was very rare that hyphae of these fungi penetrated through the barrier formed by *T. lignorum*.

In another set of experiments the fungi were grown in petri dishes containing Richards' agar. The depth of the medium in these petri dishes was about 1 cm. The two fungi *R. solani* or *R. bataticola* and *T. lignorum* were inoculated on opposite sides of the same petri dish. After about three days' growth the advancing hyphae of the two fungi met in the centre of the plate. The line of contact was clearly demarcated and was light brown in colour, turning dark brown with age. Inocula were taken from different positions in the colony so as to determine the distribution of the two fungi in the colony. Considering the line of demarcation as the central radial line, the inocula were taken from this line as well as six lines running parallel to this at a distance of $\frac{1}{2}$, $\frac{1}{2}$ and 1 cm. on either side of the central line as shown in Fig. 1.

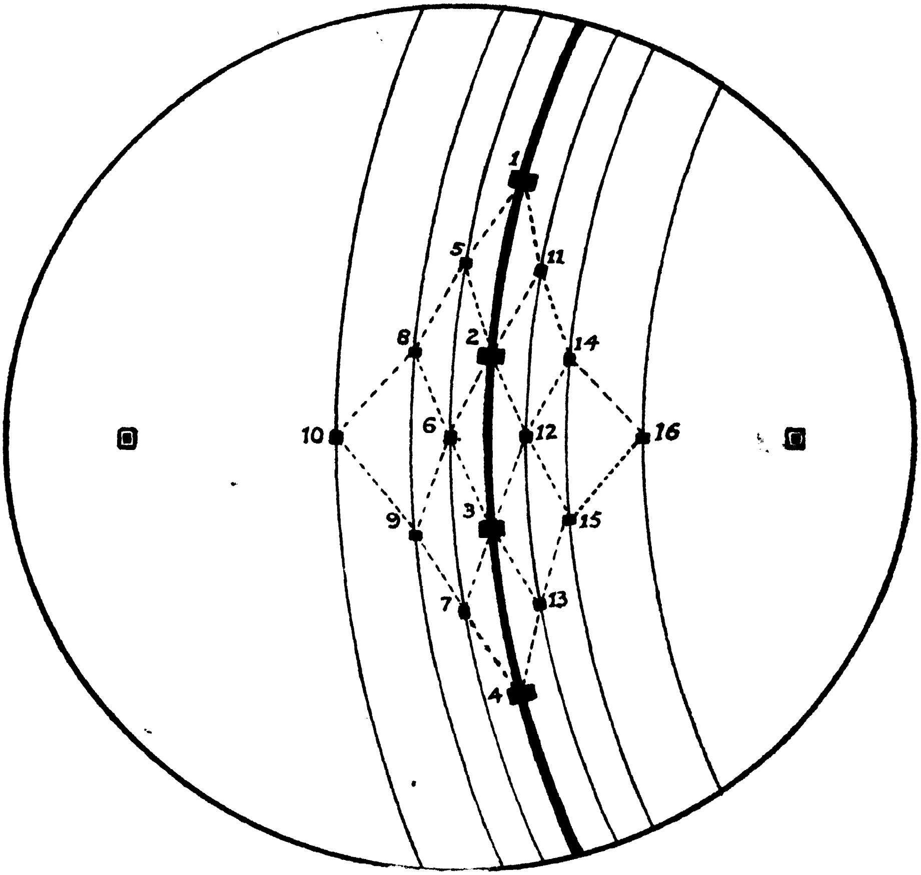


Fig. 1. Showing position of inocula

It might be mentioned that the rate of growth of *R. solani* and *R. bataticola* was retarded when the mycelium of *T. lignorum* approached close to it. *T. lignorum* continued to grow so as to cover the entire plate. After several days' further growth the brown line of contact could not be seen from the upper surface, but it was very clear from the lower surface.

Altogether 32 inocula were taken from each plate, i.e. 16 from upper surface and 16 from the corresponding positions from the lower surface after aseptically inverting the medium. The inocula were taken after 10, 18, 40 and 60 days' growth in triplicates. The results of a typical experiment are summarized in Table I.

The results show that the number of mixed inocula is greatest after 10 days' growth but diminishes as the growth progresses, whereas the frequency of occurrence of *T. lignorum* in almost a pure form increases.

TABLE I

Frequency of occurrence of R. Bataticola, R. Solani *and* T. lignorum *in mixed cultures*

Growth (days)	Surface of medium	*T. lignorum* and *R. bataticola*				*T. lignorum* and *R. solani*			
		Total inocula taken (3 plates)	Growth of mixed fungi, *R. bataticola* + *T. lignorum*	*R. bataticola*	*T. lignorum*	Total inocula taken (3 plates)	Growth of mixed fungi, *T. lignorum* + *R. solani*	*R. solani*	*T. lignorum*
10	Upper	48	18	8	22	48	14	3	31
	Lower	48	24	10	14	48	25	6	17
18	Upper	48	8	*Nil*	40	32*	3	*Nil*	29
	Lower	48	3	Do.	45	32*	2	Do.	30
40	Upper	48	7	Do.	41	48	8	Do.	40
	Lower	48	1	Do.	47	48	6	Do.	42
60	Upper	48	3	Do.	45	48	5	Do.	43
	Lower	48	2	Do.	46	48	4	Do.	44

* 2 plates only taken

After 10 days' growth 18·7 per cent inocula gave *R. bataticola* and 9·3 per cent gave *R. solani*, whereas after 18, 40 and 60 days ' growth none of the inocula yielded either *R. bataticola* or *R. solani*.

The results hold good both for upper and lower surface cultures. These cultural experiments clearly indicate that *T. lignorum* is antagonistic to the two *Rhizoctonias*. Such antagonistic effect in mixed cultures has been shown by Vasudeva [1930] for *Botrytis allii* and *Monilia fructigena*.

Another experiment was conducted in uniform Erlenmeyer flasks of 250 c. c. capacity containing 75 c. c. of Richards' solution. The fungi under study were inoculated singly and in mixtures in order to determine whether *T. lignorum* and *Aspergillus niger* would dominate the two *Rhizoctonias*. In this connection dry weights of the fungal mats of the cultures grown singly and in mixtures were taken after 15, 28, 48 and 60 days' growth. The colour and smell of the stales were noted. Observations were also made regarding the predominance of fungi in mixed cultures. The *p*H of the media was estimated before and after the growth of the fungi. The data of this experiment are summarized in Table II.

The data bring out the following points of interest :—

1. Mixed fungal mats of *T. lignorum* and *R. bataticola* are less in weight than *R. bataticola* alone throughout, i.e. after 15, 28, 46 and 60 days' growth.
2. Mixed fungal mats of *T. lignorum* and *R. solani* are less in weight than *R. solani* alone.
3. Mixed fungal mats of *A. niger* and *R. bataticola* are less in weight than *R. bataticola* alone excepting after 60 days' growth, where the growth in the mixed cultures is greater than *R. bataticola* alone. This may be explained on the basis of reduced growth after 60 days in the case of *R. bataticola*, which had fallen from 1·3 to 0·8 gm.

TABLE II

Growth of R. bataticola *and* R. solani *in liquid cultures in the presence of* T. lignorum *and* A. niger

Growth (days)	Pure				Mixed					pH of control
	Fungus	Weight of mycelium (gm.)	Stale		Fungus	Weight of mycelium (gm.)	Stale			
			pH	Colour			Fungus predominant	pH	Colour	
15	*T. lignorum*	0·145	5·7	Light orange	*T. lignorum* + *R. bataticola*	0·206	*T. lignorum*	5·8	Light orange	4·5
	R. bataticola	0·777	5·2	Light yellow	*T. lignorum* + *R. solani*	0·112	Do.	5·2	Light yellow	
	R. solani	0·152	5·8	Turbid light yellow	*A. niger* + *R. bataticola*	0·631	*A. niger*	2·3	Light lemon	
	A. niger	0·795	2·8	Lemon	*A. niger* + *R. solani*	0·792	Do.	2·5	Do.	
					R. bataticola + *R. solani*	0·669	*R. bataticola*	5·0	Dirty yellow	
28	*T. lignorum*	0·289	6·0	Deep orange	*T. lignorum* + *R. bataticola*	0·205	*T. lignorum*	6·0	Orange	4·5
	R. bataticola	1·039	4·5	Light yellow	*T. lignorum* + *R. solani*	0·117	Do.	5·7	Light orange	
	R. solani	0·495	5·6	Turbid light yellow	*A. niger* + *R. bataticola*	0·918	*A. niger*	3·0	Lemon	
	A. niger	0·959	4·4	Lemon	*A. niger* + *R. solani*	0·788	Do.	3·0	Do.	
					R. bataticola + *R. solani*	1·196	*R. solani* and *R. bataticola*	6·2	Dirty yellow	
46	*T. lignorum*	0·336	6·0	Light salmon	*T. lignorum* + *R. bataticola*	0·284	*T. lignorum*	6·0	Light salmon orange	4·5
	R. bataticola	1·031	6·0	Ivory yellow	*T. lignorum* + *R. solani*	0·350	Do.	6·2	Do.	
	R. solani	0·520	5·5	Honey yellow	*A. niger* + *R. bataticola*	0·970	*A. niger*	3·8	Primorse yellow	
	A. niger	0·908	4·5	Primorse yellow	*A. niger* + *R. solani*	0·926	Do.	3·6	Do.	
					R. bataticola + *R. solani*	0·893	*R. bataticola*	6·4	Pale pinkish buff	
60	*T. lignorum*	0·383	6·8	Salmon orange	*T. lignorum* + *R. bataticola*	0·352	*T. lignorum*	6·4	Bitter sweet orange	4·5
	R. bataticola	0·765	7·0	Crimson buff	*T. lignorum* + *R. solani*	0·356	Do.	6·4	Do.	
	R. solani	0·547	5·4	Ochraceous	*A. niger* + *R. bataticola*	0·973	*A. niger*	4·6	Primorse yellow	
	A. niger	0·910	4·7	Primorse yellow	*A. niger* + *R. solani*	0·859	Do.	4·6	Do.	
					R. bataticola + *R. solani*	0·857	*R. bataticola*	7·0	Pinkish buff	

4. Mixed fungal mats of *A. niger* and *R. solani* are throughout greater in weight than *R. solani* alone, but it may be mentioned that *A. niger* was greatly in predominance in all the cultures and no traces of *R. solani* were visible even after 15 days' growth.

5. Mixed fungal mats of *R. solani* + *R. bataticola* are greater in weight than *R. solani* alone throughout.

From the data it is clear that the growth of *R. bataticola* and *R. solani* is appreciably reduced in liquid cultures in the presence of *T. lignorum* and *A. niger*.

The *p*H of the stales from *T. lignorum*, *R. solani*, *R. bataticola* and their mixtures show that all these fungi tend to reduce the acidity of the medium.

Basal medium in the case of *A. niger* after 15 days' growth had become more acidic but after 28, 46 and 60 days' growth the *p*H of the filtrates again almost fell in line with the controls, i.e. a reduction in acidity. In the case of mixed cultures an increase in acidity occurred after 15, 28 and 46 days' growth, whereas after 60 days' growth the *p*H of the filtrates fell in line with the controls.

It might, however, be mentioned that *R. solani* and *R. bataticola* have a fairly wide range of toleration to acidity and alkalinity and show good growth between *p*H 4·0 and 8·6. Beyond these limits there is a fall in growth. *T. lignorum* and *A. niger*, show good growth between *p*H 2·8 and 8·2 with optimum growth between 4·0 and 5·0 but beyond 8·2 there is a rapid fall in growth.

This was tested on glucose-peptone agar in petri dishes. The *p*H of the medium was adjusted by the addition of malic acid and sodium bicarbonate. A range from 2·8 to 9·6 was set up.

C. Antagonistic effect of hyphae of T. lignorum *and* A. niger

It has been demonstrated that *T. lignorum* has a markedly depressing effect on *R. solani* and *R. bataticola* and that a brown line of demarcation appears at the junction of the hyphae of the two fungi when they are grown opposite to each other in the same plate.

The interaction of the hyphae of the two fungi, i.e. *T. lignorum* and *R. bataticola* or *R. solani* was studied in petri dishes containing Richards' agar.

A simple method of demonstrating their interaction was to pour the medium in such a way that the medium grades from very deep to very shallow from side to the centre of the plate. A similarly graded medium was also poured on the opposite side of the dish after the first one had set. A narrow channel was formed in the centre of the plate where the two slants met. This central line had either a very thin layer of medium, or the medium was almost absent. The two fungi were inoculated in the centre of the slants almost equidistant from the central line. Usually on the third day the hyphae of the fungi came in close proximity when a thorough microscopic examination was conducted. Such examination was continued at frequent intervals daily for several days. Study of the interaction of the fungi was also conducted on very thinly poured plates. About 7 c. c. of very hot medium was poured in the plate and vigorously shaken so as to spread the medium uniformly in an extremely thin layer. Interaction of hyphae of *R. bataticola* with hyphae of *T. lignorum* and *A. niger* was studied in detail.

Plate XIX, figs. 1-4 show various stages of interaction of *T. lignorum* and *R. bataticola* hyphae.

It was observed that the hyphae of *T. lignorum* coil round hyphae of *R. bataticola*. Later the protoplasmic contents of the attacked hyphae of *R. bataticola* coagulate, the host hyphae dissolve and a substance of granular nature is given out.

Interaction of T. *lignorum* and *R. solani* was also studied microscopically and a similar coiling round of the hyphae and dissolution of the host hyphae was observed.

Plate XX, figs. 1-5 show interaction of *A. niger* and *R. bataticola*. In this case also coiling round of hyphae of *R. bataticola* by *A. niger* was observed. The protoplasmic contents of the attacked hyphae were seen to coagulate. The attacked hyphae later on give out a granular substance, shrink, turn pale and the cell walls and cross walls disappear.

Finally a thick, deep yellow substance was observed, which seemed to break up into numerous crystal-like bodies. It is not yet clear as to how the yellowish substance is formed. These results are in accordance with the findings of Weindeling [1932] and Porter [1924] who record that in mixed culture the hyphae of one fungus may show a dissolving effect upon the hypae of the other.

(*a*) *Toxic effect of filtrates*

After having studied the effect of *T. lignorum* when grown in close proximity to *R. solani* and *R. bataticola* it was considered interesting to study the effect of the filtrates of *T. lignorum* on the growth of *R. solani* and *R. bataticola*. For this purpose *T. lignorum* was grown in Erlenmeyer flasks of 300 c. c. capacity containing 100 c. c. of Richards' solution. The growth was allowed to proceed for 60 days at 30°C. At an interval of 10 days three flasks were taken and their contents filtered through Buchner filter and centrifuged in order to remove the remaining spores and mycelium. Before using the filtrate it was ensured by miscroscopic examination that the filtrate had almost entirely been freed of the fungus. Dry weights of the fungus were taken along with the *p*H of the stale as well as of controls. All this process was carried out aseptically in sterilized apparatus in order to reduce the possibility of contamination to the minimum. The filtrate was divided into 5-c. c. lots in uniform test-tubes and these inoculated in triplicates with *T. lignorum*, *R. solani* and *R. bataticola*. Control test-tubes containing Richards' solution were also similarly inoculated.

All these cultures in test-tubes were examined for growth after six days.

Ten and 20 days' stale of *T. lignorum* did not have any marked effect on its own growth or on the growth of *R. solani* and *R. bataticola*. Depression in growth was, however, observed in 30 days' stales in the case of all the three fungi. In 40, 50 and 60 days' stales *R. solani*, *R. bataticola* and *T. lignorum* respectively failed to grow, whereas 10 days previous to failure in growth a marked reduction was noticed in the case of each fungus.

It was further shown that the toxic principle in 60-66 days' old stale is not thermostable and could be easily removed by heating. It could also be removed by dilution.

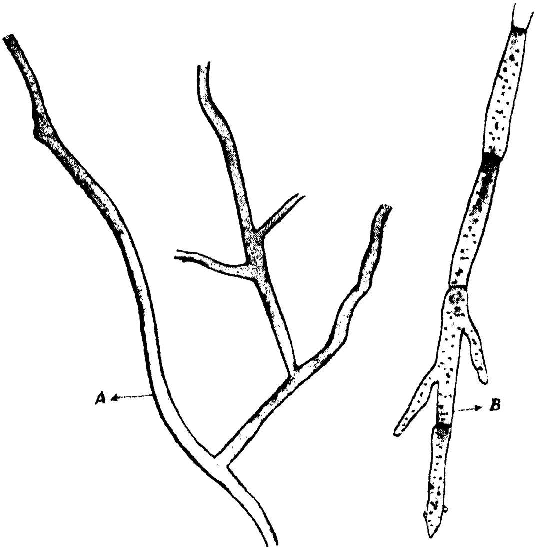


Fig. 1. (A) Hyphæ of *T. lignorum* and (B) Hyphæ of *R. bataticola*, in close proximity (×416)

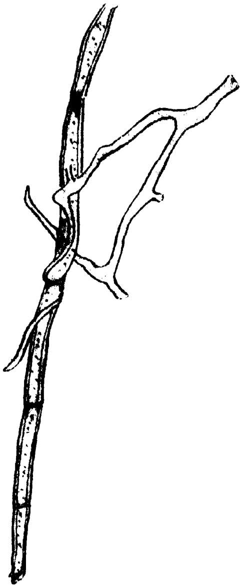
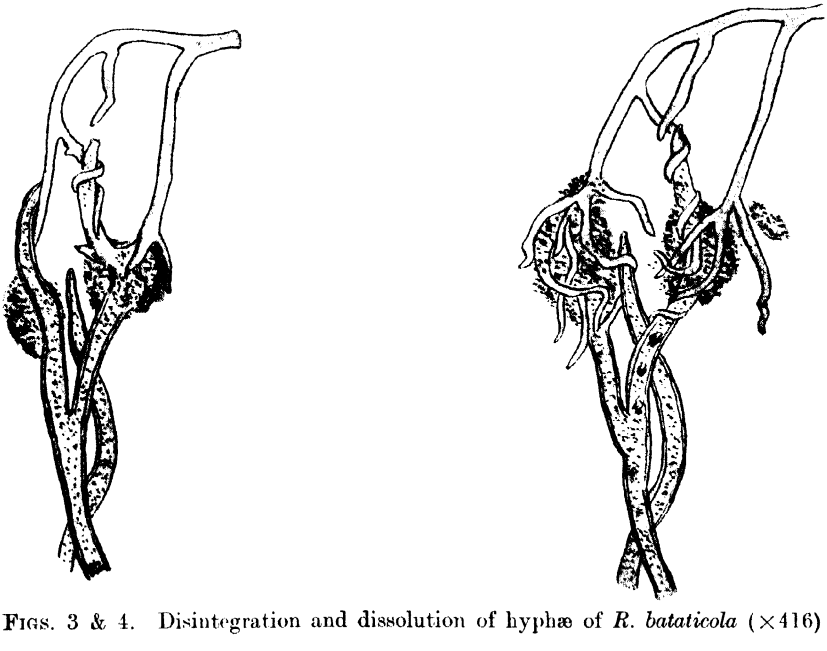


Fig. 2. Coiling round of hyphæ of . *bataticola* by *T. lignorum* (×416



Figs. 3 & 4. Disintegration and dissolution of hyphæ of *R. bataticola* (×416)

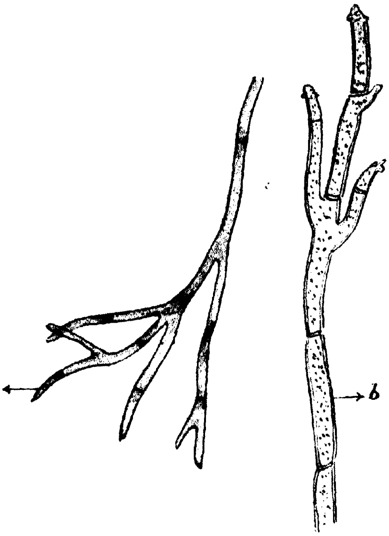


FIG. 1. Hyphæ of (*a*) A. niger, (*b*) *R. bataticola* (×416)

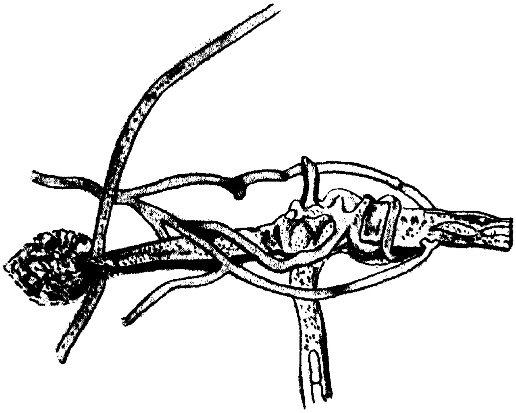
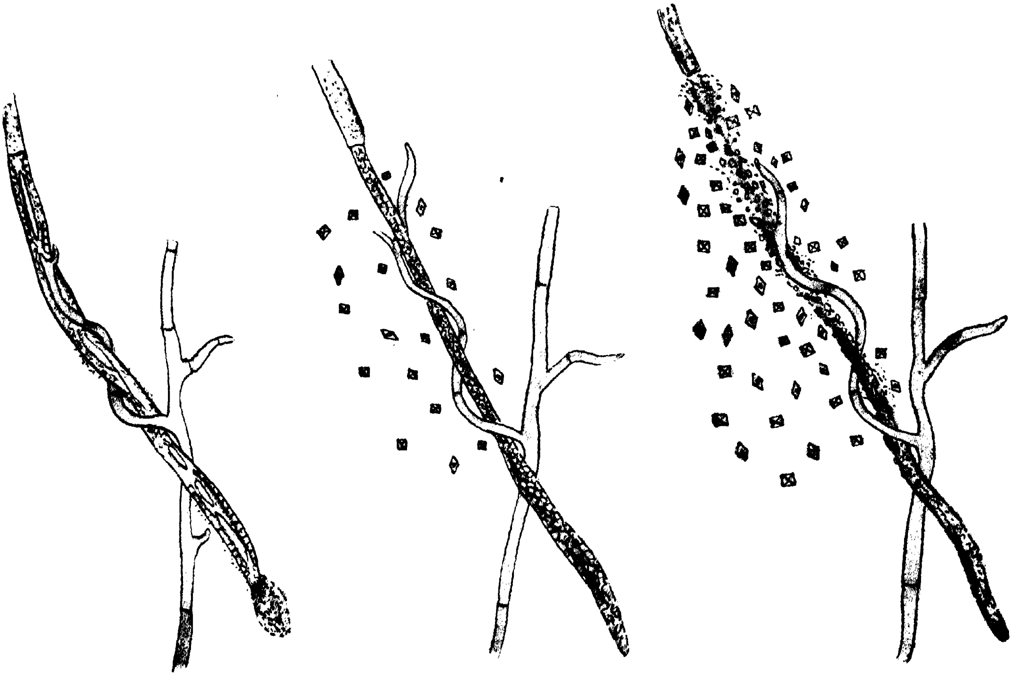


FIG. 2. Coiling of hyphæ of *A. niger* round *R. bataticola* hyphæ (×416)



FIGS. 3, 4 & 5. Shrinkage and dissolution of *R.* **bataticola** hyphæ and liberation of granular substance (×416)

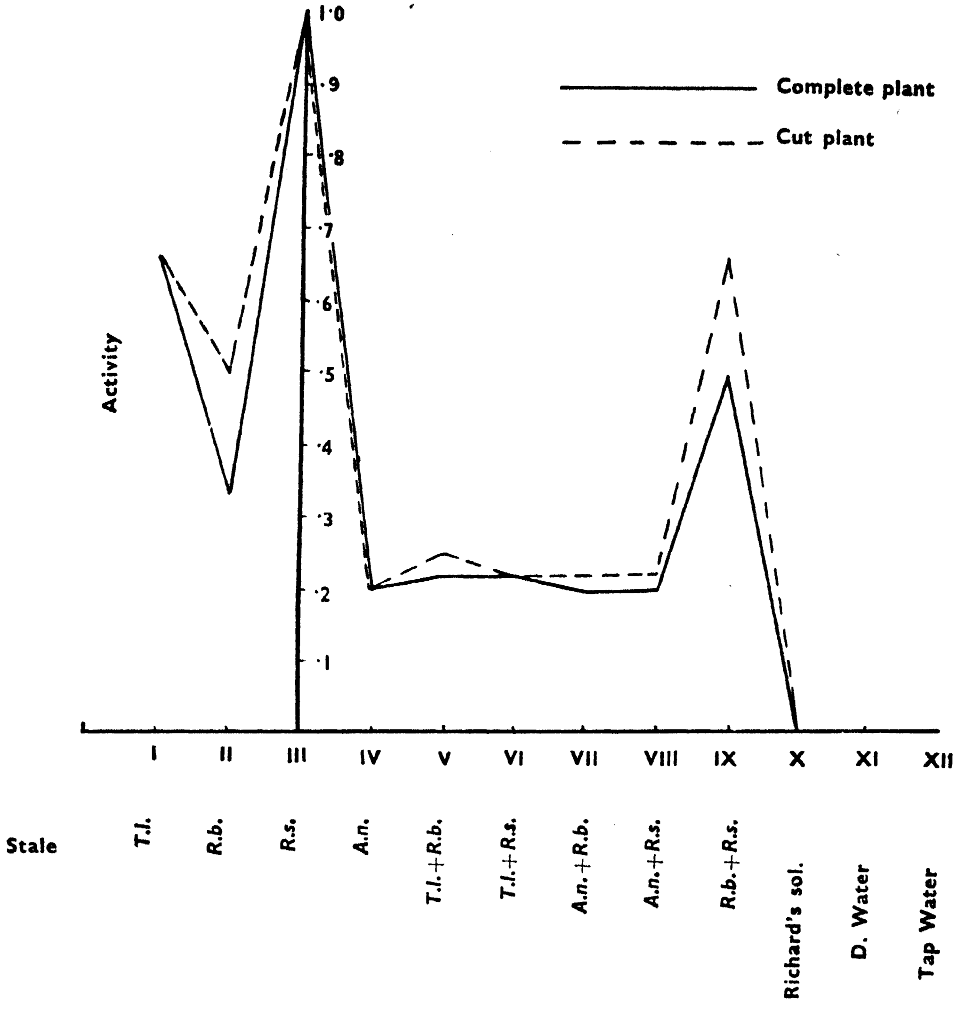


FIG. 2. Activity of various filtrates

(b) Activity of filtrates

The toxic effect of stale of various fungi when grown singly and in mixtures was studied on young cotton plants 15 days old and of variety Mollisoni 39 (*G. indicum*). The plants were removed from the soil by washing their roots so as to avoid injury to the roots and washed thoroughly in running tap water and then in sterilized distilled water. These plants were transferred to uniform specimen tubes containing 35 c. c. of 60 days old stale of various fungi. The plants were maintained in erect positions in the specimen tubes by passing them through split corks. Every effort was made to maintain aseptic conditions. Control plants were kept in Richards' solution, tap water and distilled water. The test was conducted in triplicates both for plants with roots and for plants without root-system which had been aseptically removed.

Observations regarding condition of the plants were made after every 30 minutes.

The activity of the filtrates is inversely proportional to the time required to bring about wilting of the plants.

The results of this experiment are summed up in Table III. Fig. 2 shows the activity of various filtrates.

TABLE III

Activity of filtrates

Lot No.	Stale of fungus (60 days old)	Time for wilting of complete plants (minutes)	Activity	Time for wilting of plants without roots (minutes)	Activity
I	*T. lignorum* . .	90	0·66	90	0·66
II	*R. bataticola* . .	180	0·33	120	0·50
III	*R. solani* . . .	60	1·00	60	1·00
IV	*A. niger* . . .	300	0·20	300	0·20
V	*T. lignorum* + *R. bataticola*	270	0·22	240	0·25
VI	*T. lignorum* + *R. solani*	270	0·22	270	0·22
VII	*A. niger* + *R. bataticola*	300	0·20	270	0·22
VIII	*A. niger* + *R. solani* .	300	0·20	270	0·22
IX	*R. bataticola* + *R. solani*	120	0·50	90	0·66
X	Control Richards' solution	..	0·00	..	0·00
XI	Distilled water . .	..	0·00	..	0·00
XII	Tap water. . .	..	0·00	..	0·00

The results show that the activity of filtrates of *R. solani* and *R. bataticola* is reduced when these fungi are grown in mixtures with *T. lignorum* and *A. niger*. The results are in accordance with the findings of Vasudeva [1935] for the filtrates of mixed cultures of *Botrytis cinerea*. Such reduction in activity could probably be ascribed to the staling phenomenon or to the parasitic action of *T. lignorum* and *A. niger* or both.

SUMMARY

1. The presence of *Trichoderma lignorum* and *Aspergillus inger* in the inoculum of *Rhizoctonia bataticola* and *R. solani* greatly interferes with the growth of the latter fungi.

2. The hyphae of *Trichoderma lignorum* and *Aspergillus niger* show a dissolving effect on the hyphae of *Rhizoctonia bataticola* and *R. solani*.

3. The activity of filtrates of *Rhizoctonia bataticola* and *R. solani* is reduced when these fungi are grown mixed with *Trichoderma lignorum* and *Aspergillus niger*.

ACKNOWLEDGEMENTS

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REFERENCES

Porter, C. L. (1924). *Proc. Ind. Acad. Sci.* **36**, 259-60

Ridgway (1912). *Colour standards and nomenclature*

Vasudeva, R. Sahai (1930). *Ann. Bot.* **44**, 557-64

———————— (1935). *J. Ind. Bot. Soc.* **14**, 71-83

———————— (1936). *Ind. J. Agric. Sci.* **6**, 904-16

Weindling, R. (1932). *Phytopath.* **22**, 837-45

SOME BREEDING INVESTIGATIONS ON LINSEED (*LINUM USITATISSIMUM* L.) IN THE PUNJAB

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LINSEED is an important crop in certain parts of the Punjab, occupying an area of about 32,000 acres annually. It is grown chiefly in the districts of Kangra, Gurdaspur, Hoshiarpur and Sialkot, where it constitutes about 75 per cent of its total area in the province. The crop is generally sown in October-November and is harvested in April, being grown entirely for the oil in its seed.

In view of the importance of linseed as an oilseed crop in the Punjab, its botanical study was started at Lyallpur during 1932. An examination then made of the linseed crop grown by the farmers in different parts of the province revealed it to be an admixture of several types which have been classified into 33 distinct unit species on the basis of differences in the morphological characters of the plants. A few types selected from amongst these unit species have already proved to be superior to the local mixed strains both in yield and oil content of seeds, and are, therefore, likely to replace, in due course, the mixed strains already under cultivation in the province. It may, however, be noted that none of the Punjab types happens to possess yellow or fawn colour of seeds and, since these colours are considered to be correlated with greater quantity and better quality of oil and are therefore liked in trade, hybridization between high-yielding, brown-seeded Punjab types and yellow- and fawn-seeded Pusa hybrids, which as such have not given satisfactory results in the Punjab, was resorted to. The study of these crosses permitted observations being made on the mode of inheritance of several morphological characters, and the purpose of the present paper is to record data so far collected and the results obtained.

MATERIAL AND METHODS

For the purpose of these studies reciprocal crosses were made between four promising Punjab types and two Pusa hybrids. The detailed morphological characters of the parental types employed are as follows :

Name of parent	Habit of growth	Opening of flowers	Colour of					
			Petals	Filaments	Anthers	Style	Stigma	Seed
Pusa LH 10 .	Erect and open	Complete .	White	Blue	Yellow	Blue	Blue with purple shade	Yellow
Pusa LH 21 .	Erect and open	Complete .	Blue	Blue	Blue	Blue	Blue	Fawn
Punjab T 4 .	Spreading and open	Partial .	White	White	Yellow	White	White .	Reddish brown
Punjab T 5 .	Spreading and open	Partial .	White	White	Yellow	White	White .	Reddish brown
Punjab T 22 .	Erect and open	Complete .	Blue	Blue	Blue	Blue	Blue .	Brown
Punjab T 23 .	Spreading and open	Complete .	Blue	Blue	Blue	Blue	Blue .	Brown

Crosses between the above-mentioned types and hybrids were made during 1935-36 and the F_1, F_2 and F_3 progenies were grown in the oilseeds experimental area at Lyallpur during subsequent years. For raising F_2 and F_3 only selfed seed obtained by bagging plants with fine muslin bags was used.

In the various crosses made, the inheritance of the following characters has been studied and an attempt has also been made for working out the linkage relationship of these characters.

1. Colour of petal
2. Shape of petal and opening habit of flowers
3. Colour of anthers
4. Colour of seed

EXPERIMENTAL RESULTS

1. *Inheritance of petal colour*

The detailed results of segregation obtained in the case of each of the four crosses studied are given below :

(*i*) *LH 10 × T 22*.—LH 10 has white petals with faint violet veins at the base. The petals of T 22 are blue in colour. The F_1 had blue petals like T 22. The F_2 population showed the following phenotypes of petal colour and their frequencies.

	Segregation in F_2			Value of P
	Blue	White	Total	
1937-38—				
Observed	142	53	195	0·50
Expected on 3 : 1 ratio . . .	146·25	48·75	195	
1938-39—				
Observed	264	74	338	0·20
Expected on 3 : 1 ratio . . .	253·5	84·5	338	

In F_3 the following segregations were observed during 1938-39 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
15 cultures from plants with blue petals like T 22	Pure blue like T 22	6	5·0
	3 blue : 1 white .	9	10·0
15 cultures from plants with white petals like LH 10	Pure white . .	15	15

(*ii*) *LH 10* × *T 23*.—LH 10 has white petals with faint violet veins a the base. The petals of T 23 are blue. The F_1 had blue petals like T 23 The following phenotypes of petal colour and their frequencies were observed in F_2 :—

	Segregation in F_2			Value of P
	Blue	White	Total	
1937-38—				
Observed	1,504	526	2,030	0·36
Expected on 3 : 1 ratio . . .	1,522·5	507·5	2,030	
1939-40—				
Observed	911	314	1,225	0.62
Expected on 3 : 1 ratio . . .	918·75	306·25	1,225	

In F_3 the following segregations were observed in the year 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
52 cultures from plants with blue petals like T 23	Pure blue . .	16	17·3
	3 blue : 1 white .	36	34·6
113 cultures from plants with white petals like LH 10	Pure white . .	113	113

(*iii*) *LH 21 × T 4.*—LH 21 has blue petals and T 4 has white ones. The F_1 had blue petals like LH 21. The F_2 population showed the following phenotypes of petal colour and their frequencies in the year 1938-39 :—

	Segregation in F_2			Value of *P*
	Blue	White	Total	
Observed	405	147	552	0·40
Expected on 3 : 1 ratio . . .	414	138	552	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
22 cultures blue flowered in F_2 . .	Pure blue . .	6	7·33
	3 blue : 1 white .	16	14·66
8 cultures white flowered in F_2 . .	Pure white . .	8	8

(*iv*) *LH 21 × T 5.*—The petals of LH 21 are blue in colour but those of T 5 are white. The F_1 had blue petals like LH 21. The F_2 progenies showed the following phenotypes of petal colour and their frequencies in the year 1938-39 :—

	Segregation in F_2			Value of *P*
	Blue	White	Total	
Observed	367	111	478	0·39
Expected on 3 : 1 ratio . . .	358·5	119·5	478	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
49 cultures blue flowered in F_2 . .	Pure blue . .	13	16·33
	3 blue : 1 white .	36	32·66
21 cultures white flowered in F_2 . .	Pure white . .	21	21

Segregation in F_2 and the behaviour of F_3 progenies in all the four crosses under study show clearly that there is a single-factor difference between the blue and white colours of petal.

2. *Inheritance of the opening habit of flowers*

Flowers of T 22, T 23, LH 10 and LH 21 have broad petals and open completely, but the flowers of T 4 and T 5 have 'crimped' petals and open partially. Observations with regard to the opening habit of the flowers were made in the crosses LH 21 × T 4 and LH 21 × T 5. The flowers of F_1 were broad petalled and opened completely. In F_2 and F_3 progenies all the flowers with blue petals had broad petals and opened completely, while all the white flowers were 'crimped' and opened partially, showing a complete linkage between petal colour and the opening habit of the flowers. Like petal colour, therefore, there is only a monogenic difference between the broad and 'crimped' petal characters.

3. *Inheritance of anther colour*

All the plants of the three parents with blue petals had blue colour of anthers, while all the three parents having white petal colour had yellow anthers. The anther colour in the case of all the F_1 plants was blue. In F_2 and F_3 progenies the anther colour was found to be completely associated with the petal colour; all the plants with the blue flowers had blue colour of anthers, while those with white petal colour had yellow anthers, showing a complete linkage between the characters concerned and also a monogenic difference between blue and yellow anther colours.

4. *Inheritance of seed colour*

The results of seed colour inheritance obtained in the case of different crosses are described below :—

(*i*) *LH 10 × T 22*.—LH 10 has bold yellow seeds, while T 22 has bold brown seeds. The F_1 progenies had bold brown seeds. The following were the observed phenotypes for seed colour and their frequencies in F_2 :—

	Segregation in F_2					Value of of *P*
	Brown	Grey	Fawn	Yellow	Total	
1937-38—						
Obrserved . . .	117	39	33	6	195	0·25
Expected on 9 : 3 : 3 : 1 ratio	109·69	36·56	36·56	12·19	195	
1938-39—						
Observed . . .	203	55	60	20	338	0·53
Expected on 9 : 3 : 3 : 1 ratio	190·125	63·375	63·375	21·125	338	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
14 cultures brown seeded in F_2 . .	Pure brown . .	2	1·55
	Like F_2 . .	8	6·22
	3 brown : 1 grey .	2	3·11
	3 brown : 1 fawn .	2	3·11
30 cultures grey seeded in F_2 . .	Pure grey . .	11	10
	3 grey : 1 yellow .	19	20
17 cultures fawn seeded in F_2 . .	Pure fawn . .	12	5·66
	3 fawn : 1 yellow .	5	11·33
14 cultures yellow seeded in F_2 . .	Pure yellow . .	14	14

(*ii*) *LH 10 × T 23.*—LH 10 has yellow seeds and T 23 has brown seeds. The F_1 had brown seeds like T 23. In the F_2 progenies four different phenotypes of seed colour were observed with the following frequencies :—

	Segregation in F_2					Value of *P*
	Brown	Grey	Fawn	Yellow	Total	
1938-39—						
Observed . . .	1,137	392	379	122	2,030	0·90
Expected on 9 : 3 : 3 : 1	1,141·91	380·61	380·61	126·87	2,030	
1939-40—						
Observed . . .	645	220	207	61	3	0·61
Expected on 9 : 3 : 3 : 1	637·31	212·44	212·44	70·81	1,133	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
33 cultures brown seeded in F_2	Pure brown	4	3.66
	Like F_2	12	14·66
	3 brown : 1 grey	6	7·33
	3 brown : 1 fawn	11	7·33
17 cultures grey seeded in F_2	Pure grey	5	5·66
	3 grey : 1 yellow	12	11·32
10 cultures fawn seeded in F_2	Pure fawn	3	3·33
	3 fawn : 1 yellow	7	6·66
28 cultures yellow seeded in F_2	Pure yellow	28	28

(*iii*) *LH 21 × T 4*.—LH 21 has got fawn colour of seeds while the seeds of T 4 are reddish brown in colour. The seeds of the F_1 progenies were reddish brown in colour like T 4. In F_2 the following segregation for seed colour was observed in the year 1938-39 :—

	Segregation in F_2			Value of *P*
	Reddish brown	Fawn	Total	
Observed	415·0	137·0	552	0·92
Expected on 3 : 1 ratio	414·0	138·0	552	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and nature of parent plants	Segregation	Frequencies	
		Observed	Expected
14 cultures brown seeded in F_2	Pure brown	5	4·66
	3 brown : 1 fawn	9	9·33
16 cultures fawn seeded in F_2	Pure fawn	16	16

(*iv*) *LH 21 × T 5*.—LH 21 has got fawn colour of seeds, while the seeds of T5 are reddish brown. All the plants in the F_1 progenies had brown seeds and in F_2 the following segregation was observed for the seed colour during 1938-39 :—

	Segregation in F_2			Value of *P*
	Reddish brown	Fawn	Total	
Observed	320·0	108·0	428	0·74
Expected on 3 : 1 ratio . . .	321·0	107·0	428	

In F_3 the following segregations were observed during 1939-40 :—

Number of cultures and the nature of parent plants	Segregation	Frequencies	
		Observed	Expected
17 cultures brown seeded in F_2 . .	Pure brown . .	6	5·66
	3 brown : 1 fawn .	11	11·34
53 cultures fawn seeded in F_2 . .	Pure fawn . .	53	53

The above results show that two factors are responsible for the brown colour of seed. In the case of crosses between the brown- and yellow-seeded types four different phenotypes, viz. brown, grey, fawn and yellow, appear in the ratio of 9 : 3 : 3 : 1 in F_2. Similar results have been recorded by Tammes [1928] and Shaw *et al.* [1931]. Fawn colour of seed has behaved as a simple recessive to brown colour, proving a monogenic difference between the two colours.

It is of special interest to note that as a result of these studies a large number of pure-breeding yellow- and fawn-seeded hybrids having desirable combination of other characters have now become available. These are being tried with a view to selecting the best of these for general cultivation.

5. *Linkage between flower and seed colours*

It has been shown above that there is a single-factor difference between blue and white flower colours, while brown seed colour is controlled by two factors. It will be interesting to find out the relationship of the genes responsible for the seed and flower colours respectively when the segregation of both the characters is considered together. In the case of independent assortment of the genes responsible for the flower and seed colours a tri-hybrid ratio, viz. 27 : 9 : 9 : 9 : 3 : 3 : 3 : 1 should be expected. The observed and expected frequencies of the various phenotypic classes obtained for each of the two crosses studied when the segregation of flower and seed colour is considered together are given in Table I.

TABLE I

Observed and expected frequencies of various phenotypic classes

Cross		Frequencies of various phenotypic classes								Total
	Phenotypes	GMD	GMd	GmD	gMD	Gmd	gMd	gmD	gmd	
	Flower colour	blue	white	blue	blue	white	white	blue	white	
	Seed colour	brown	brown	grey	fawn	grey	fawn	yellow	yellow	
LH 10 × T 22	Observed .	216	14	7	66	68	8	2	11	392
	Expected .	165·38	55·12	55·12	55·12	18·38	18·38	18·38	6·12	392
	$\frac{(O-E)^2}{E}$	15·49	30·68	42·01	2·14	134·02	5·85	14·59	3·88	245·7
LH 10 × T 23	Observed .	629	16	31	192	189	15	6	55	1,133
	Expected .	477·98	159·33	159·33	159·33	53·11	53·11	53·11	17·70	1,133
	$\frac{(O-E)^2}{E}$	47·71	12·89	103·36	6·70	347·69	27·35	41·79	81·84	669·33

It will be observed from Table I that the frequency of certain phenotypic classes has considerably fallen short of the expectation, while the frequency of certain other classes is far in excess of the values expected according to the trihybrid ratio referred to above. The value of χ^2 which is very high in both the crosses also shows that the fit of the observed and expected values is by no means good. Such large deviation would obviously lead to the conclusion that the genes responsible for seed and flower colours are not inherited independently of each other.

With a view to finding out the exact linkage relationship of the gene **D** responsible for the appearance of blue colour in the flowers with each of the genes **G** and **M** both of which together produce the brown colour of seed as discussed later on, the F_2 data given in Table I were analysed in details. The results obtained are described below :—

(*a*) *Linkage of flower-colour factor **D** with seed-colour factor **M**.*—The observed and expected frequencies of the four phenotypic classes when both these factors are considered together are given in Table II from which it will be observed that the frequencies of the double dominant and double recessive classes in both the crosses are far in excess of the expected values, while the frequencies of the middle classes fall short of the expectation.

The value of χ^2 is extremely high in both the crosses. This clearly shows that flower factor **D** and seed-colour factor **M** are not inherited independently. Evidently, therefore, these two factors are linked together.

The theoretical frequencies of the various phenotypes have been calculated according to the product-ratio method of Fisher. This method has been found to be the most efficient by Alam [1929] who has recommended this for general use. The results are given in Table III.

TABLE II

Observed and expected frequencies of the four phenotypic classes in crosses LH 10 × T 22 and LH 10 × T 23

Cross	Frequencies of various phenotypic classes					Total
	Phenotypes Flower colour Seed colour	**MD** blue brown and fawn	**Md** white brown and fawn	**mD** blue grey and yellow	**md** white grey and yellow	
LH 10×T 22 .	Observed . .	282	22	9	79	392
	Expected on 9 : 3 : 3 : 1 ratio	220·5	73·5	73·5	24·5	392
	$\frac{(O-E)^2}{E}$	16·05	36·08	56·60	123·76	232·49
LH 10×T 23 .	Observed . .	821	31	37	244	1,133
	Expected on 9 : 3 : 3 : 1 ratio	637·31	212·44	212·44	70·81	1,133
	$\frac{(O-E)^2}{E}$	52·94	154·96	144·88	423·59	776·37

TABLE III

Theoretical frequencies calculated according to Fisher's product-ratio method

Cross	Frequencies of various phenotypes						Value of P^2	Cross-over per-centage
	Phenotypes Flower colour Seed colour	**MD** blue brown and fawn	**Md** white brown and fawn	**mD** blue grey and yellow	**md** white grey and yellow	Total		
LH 10 × T 22	Observed .	282·00	22·00	9·00	79·00	392	0·8529	7·65
	Calculated.	279·59	14·41	14·41	83·59	392		
	$\frac{(O-C)^2}{C}$	0·02	3·99	2·03	0·25	6·29		
LH 10 × T 23	**Observed .**	821·00	31·00	37·00	244·00	1,133	0·8795	6·72
	Calculated.	815·62	34·00	34·00	249·12	1,133		
	$\frac{(O-C)^2}{C}$	0·03	0·26	0·26	0·10	0·65		

The above results show that the flower-colour factor **D** is partially linked with the seed-colour factor **M**, the two having a cross-over value of nearly 7 per cent.

(*b*) *Linkage of flower-colour factor* **D** *with seed-colour factor* **G**.—The observed and theoretical frequencies of the various phenotypic classes when both these factors are considered together are given in Table IV. It is assumed that both these factors are inherited independently of each other.

TABLE IV

Observed and theoretical frequencies of the various phenotypic classes in crosses LH 10 × T 22 and LH 10 × T 23

Cross	Frequencies of various pehnotypes					Total
	Phenotypes	**GD**	**Gd**	**gD**	**gd**	
	Flower colour	blue	white	blue	white	
	Seed colour	brown and grey	brown and grey	fawn and yellow	fawn and yellow	
LH 10 ×T 22	Observed . .	223·00	82·00	68·00	19·00	392·00
	Expected on 9 : 3 :3 : 1 ratio	220·50	73·50	73·50	34·50	392·00
	$\frac{(O-E)^2}{E}$	0·03	0·99	0·41	1·23	2·66
LH10 × T23	Observed . .	660·00	205·00	198·00	70·00	1,133·00
	Expected on 9 : 3 : 3 : 1 ratio	637·31	212·46	212·46	70·81	1,133·00
	$\frac{(O-E)^2}{E}$	0·81	0·26	0·98	0·01	2·06

In both of these crosses the value of χ^2 is very small and the values of *P* from Fisher's table are 0·45 and 0·56 for the crosses L H 10 × T 22 and L H 10 × T 23 respectively. This clearly shows that there is no linkage between the flower-colour factor **D** and seed-colour factor **G**.

Further support is lent to the above-mentioned conclusions from the study of the crosses LH 21 × T 4 and LH 21 × T 5. LH 21 has got blue petal colour and fawn seed colour. Types 4 and 5 have got white petal colour and brown seed colour. The observed and expected frequencies of the four phenotypic classes in each of these crosses are presented in Table V.

TABLE V

Observed and expected frequencies of the four phenotypic classes in crosses LH 21 × T 4 and LH 21 × T 5

Cross	Frequencies of various phenotypes					Total	Value of P
	Phenotypes Flower colour Seed colour	**GD** blue brown	**Gd** white brown	**gD** blue fawn	**gd** white fawn		
LH 21 × T 4	Observed . .	275·00	102·00	97·00	33·00	507	0.69
	Expected on 9 : 3 : 3 : 1 ratio	285.19	95·06	95·06	31·69	507	
	$\frac{(O-E)^2}{E}$	0.36	0·51	0·04	0·54	1·45	
LH 21 × T 5	Observed . .	255·00	72·00	85·00	23·00	435	0·50
	Expected on 9 : 3 : 3 : 1 ratio	244·69	81·56	81·56	27·19	435	
	$\frac{(O-E)^2}{E}$	0·43	1·12	0·15	0·64	2·34	

As is evident from the values of χ^2 and P given in the last two columns of Table V, the fit of the observed frequencies with those expected on dihybrid ratio of 9 : 3 : 3 : 1 is quite good. This again confirms the conclusions drawn from the study of the first two crosses that flower factor **D** has got no linkage with seed-colour factor **G**.

DISCUSSION OF RESULTS

Tammes [1928] has determined eight hereditary factors, **A**, **B**-1, **B**-2, **C**, **D**, **E**, **F** and **K**, which influence the colour and its distribution in the petals. According to her findings, three of the factors **B**-1, **B**-2 and **C** are basal factors necessary to produce colour in the petals. If any one of them is recessive, the petal colour becomes white. Factors **D** and **F** determine the tint of the petals which may be pink, lilac, etc. Factors **A** and **E** are colour intensifiers, **E** having a stronger effect than **A**. The factor **K** is responsible mainly for the distribution of colour on the petals, its presence making the petal uniformly coloured. In its absence the colour is mainly restricted to upper edge. Different combinations of these hereditary factors yield, besides white forms, 32 genotypically different coloured forms.

Shaw *et al.* [1931] have also investigated the inheritance of flower and seed colours in the varieties of Indian linseed in addition to studying the behaviour of style and stigma colours. These authors have postulated some important deviations in the action and interaction of the factors governing different characters. According to their view there are only seven factors, namely **B**, **C**, **D**, **E**, **F**, **K** and **N**, which control the flower colour. Three of these factors, viz. **C**, **D** and **E**, also control the shape of the petal, it being 'crimped' when all of these factors are present. The anther colour depends upon the action of factor **H** with two other factors which determine petal colour. The basal colour of seed-coat is considered by these authors to be yellow which is transformed into fawn by the presence of two factors, **M** and **D**. In the presence of an additional factor **G** the fawn colour changes to brown. In absence of **D** and presence of **G** the seed-coat colour is grey irrespective of the presence or absence of **M**. The factor **X** intensifies the seed-coat colour.

It is of special interest to note that in the crosses studied by Shaw *et al.*, they found complete linkage of brown and fawn seeds with blue or lilac petals and of grey and yellow seeds with white and pink phenotypes. In contrast to this our results given above show conclusively that the complete linkage between flower colour and seed colour as borne out by Shaw's results is not valid, as is evident from the fact that phenotypes having combination of blue flower with grey seed and that of white flower with fawn seed appear in F_2 progenies of each of the crosses L H 10 × T 22 and L H 10×T 23. In the light of these results, therefore, the hypothesis postulated by Shaw *et al.* regarding the various factors controlling different seed colours requires to be modified. From our results it is logical to believe that only two factors, **G** and **M**, control the seed colour. When both these factors are absent, the seed colour is yellow. When only **M** is present, it changes the seed colour to fawn, while in presence of **G** alone the seed colour is grey. When both **M** and **G** are present together, the seed colour is brown. Our results further show that the seed-colour factor **M** is linked with flower factor **D** though not completely, the cross-over value between the two being nearly 7 per cent. The other seed factor, viz. **G**, is inherited independently of the flower-colour factor **D**.

From the results reported in this paper it is not possible to deduce any definite genetical formulæ for the constitution of the various parental types used in crossing, but the monofactorial segregation for flower colour and both mono and bifactorial segregations for seed colour as well as the complete linkage between petal colour and anther colour can be explained by assuming the following constitutions of the parental types concerned using the same letters to represent the various colour factors as suggested by Shaw [1931].

Types	Petal colour	Shape of petal	Anther colour	Seed colour	Constitution
LH 10	White	Flat	Yellow	Yellow	**BCdEFKNHmg**
LH 21	Blue	Flat	Blue	Fawn	**BCDEFKNHMg**
Punjab T 4 and T 5 .	White	Crimped	Yellow	Brown	**bCDEFKNHMG**
Punjab T 22 and T 23 .	Blue	Flat	Blue	Brown	**BCDEFKNHMG**

SUMMARY

(1) The results of studies on the inheritance of characters as obtained from the crosses made between a few Punjab types and Pusa hybrids have been described and as a result of these investigations, the following important conclusions can be drawn :

(*a*) Blue and white colours of petals behave as simple allelomorphs and segregate according to the monohybrid ratio of 3 : 1.

(*b*) The yellow colour of anthers was completely associated with the white colour and ‘ crimped ’ shape of petals. Similarly the blue colour of anthers was completely linked with the blue colour and flat shape of the petal in all the crosses studied.

(*c*) Two factors (**M** and **G**) are responsible for the brown colour of seed. In the case of crosses between the brown and yellow-seeded types, four different phenotypes, viz. brown, grey, fawn and yellow, have been found to appear in the ratio of 9 : 3 : 3 : 1 in the F_2 progenies.

(*d*) The fawn colour of seed behaves as simple recessive to brown.

(*e*) One of the two genes responsible for the production of brown colour of seeds was found to be linked with the gene producing blue colour in petals. The other gene of seed colour has got no association with the petal colour.

(2) A large number of new pure-breeding hybrids having combination of yellow and fawn colours of seed with other desirable characters have now become available.

REFERENCES

Alam, M. (1929). *Mem. Dept. Agric. Ind.* (*Bot. Ser.*) **18**, No. 1

Shaw, F. J. F. ; Khan, A. R. and Alam, M. (1931). *Ind. J. Agric. Sci.* **1**, 1-57

Tammes, T. (1928). *Bibliographia Genetica* **4**, 1-18

OBSERVATIONS ON *APHELINUS MALI* HALD. IN THE PUNJAB

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WOOLLY aphis (*Eriosoma lanigerum* Hausm.) was introduced into the Punjab in 1909. It is at present confined to the hilly tracts and is found in Bajaura, Bandrole, Dobi, Jubbal State, Kasauli, Koti State, Kulu, Manali, Naggar, Niramitii, Raison, Karjan, Katrain, Kotgarh, Kot Khai, Mashobra, Shirir, Simla and Solan [Rahman and Khan, 1941]. It is destroyed by serveral predators but none of them exercises an effective check over it. Insecticidal and other control methods tried against it, though successful, were found to be expensive. It was, therefore, decided to introduce *Aphelinus mali* Hald. for its control. The parasite was imported from the Franham House Laboratory, Franham Royal, Bucks, England, at the suggestion, and through the help, of the Imperial Council of Agricultural Research, New Delhi,* by M. Afzal Husain, the then Entomologist to Government, Punjab, Lyallpur. In the first consignment (despatched from England in June 1936 and received in Kulu in August 1936) all the parasites emerged and perished on the way. In August 1937, four consignments which were despatched and received in succession (by air mail) yielded living adult parasites. On their arrival at Kulu they were supplied with woolly aphis on infested twigs in a wire-gauze cage lined with voile cloth.† The first batch of adult parasites was liberated in a severely infested orchard of 40 trees at Raison on 5 September 1937. By 11 September 1937 they had parasitized 29 woolly aphis. Afterwards the parasite established and quickly distributed itself in many of the infested orchards of the Kulu valley. Information presented in this paper was acquired during the course of acclimatizing the parasite in the Punjab.

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*The help of the Council and that of the authorities of the Franham House Laboratory is gratefully acknowledged.

†The parasite was established in the Kulu valley as follows :—

A wire-gauze (with 144 meshes per sq. inch) cage 10 ft. × 7 ft. × 7 ft. was put up in a heavily infested orchard prior to the arrival of the parasite from England. It was lined with voile cloth to safeguard against its early and premature escape. Apple twigs covered with woolly aphis were cut off the trees and planted in the cage. When the parasite had become sufficiently numerous, a hole of about 4 in. diameter was made in the cloth to allow it to escape.

ALTERNATIVE HOSTS

Elsewhere *A. mali* Hald. has been reported from about 22 different kinds of aphids [Greenslade, 1936]. In the Punjab we offered the following species of aphids to it but it did not parasitize any of them :—

(1) *Aphis laburni* Kalt., (2) *Rhopalosiphum* sp., (3) *Rhopalosiphum pseudobrassicae* Davis, (4) *Anuraphis* sp., (5) *Prociphilus oriens* Mordov., (6) *Pemphigella aedificator* Buckt., (7) *Eriosoma* sp. (on elm), (8) *Brevicoryne brassicae* L., (9) *Myzus persicae* Sulz., (10) *Myzus cerasi* F., (11) *Macrosiphum rosaeformis* Das., (12) *Callipterus juglandis* Frisch., and (13) *Shivaphis celti* Das. We have not found it on any other aphid in nature. It is, therefore, concluded that in the Punjab *A. mali* is specific to woolly aphis.

LIFE-HISTORY

On an average the adult parasites live for seven to eight days. They feed on honeydew produced by the woolly aphis. They 'sting' the host, usually near about the mid-dorsal area of the abdomen, two to four days after emergence.

Life-cycle.—The duration of the life-cycle of the parasite depends upon the season as is seen from Table I.

TABLE I

Duration (in days) of the life-cycle of A. mali *Hald. at Kulu*

Date of egg-laying	Date of emergence of adults	Duration (in days) of life-cycle
8-10 March	2-12 April	25-33
15-18 March . . .	10-12 April . . .	25-26
3-20 April	28 April-15 May . . .	25
3-24 May	23 May-19 June . . .	20-26
12-27 June	30 June-12 July . . .	15-18
12-27 July	27 July-7 August . .	11-15
2-25 August . . .	13 August-4 September .	10-11
5-8 September . . .	17-24 September . .	12-16
18-20 September . .	1-8 October . . .	13-18
30 September-15 October .	8-24 March . . .	159-160

During June-October the life-cycle is completed in 10-18 days and in March-June in 20-33 days.

The duration of various stages in the life-cycle of the parasite depends upon the season. For example, eggs hatch out in two to three days in March-May, one to two days in June-August and six to seven days in October, while the larvae are full-fed in 8-15 days in March-June, four to six days in July-August, six to seven days in September-October and 121-123 days in October-February, and the pupal stage occupies 11-15 days in March-June, 6-10 days in July-early October and 22-30 days in February-March.

SEASONAL HISTORY

At altitudes of 4,000—5,000 ft. the adult parasites appear on the wing usually in the first week of March. From March to November all the stages are present in the orchards. During this period it passes through 15 broods as follows :—March ; April ; two broods in May ; June ; June-July ; July ; July-August ; two broods in August ; August-September ; two broods in September ; October ; and November. Elsewhere a maximum of 12 generations in a year is recorded [Greenslade, 1936]. From the middle of November to mid-February, the parasite hibernates as a grub in the body of the host. These grubs change into pupae in the second half of February from which adults appear in the first week of March.

STAGE AND NUMBER OF WOOLLY APHIS PARASITIZED

A. mali Hald. attacks wingless adults and 4th stage nymphs commonly and 3rd stage nymphs rarely. It never attacks winged adults and 1st and 2nd stage nymphs. It usually attacks the aerial forms only, as it is unable to penetrate the soil to get at the root forms ; but if they are exposed, they are also attacked readily and with equal severity.

In order to study the number of woolly aphis parasitized by a single female parasite they were liberated on infested twigs in glass tubes, the twigs being changed every third day. The results of these observations are presented in Table II.

During the period of maximum activity one female may parasitize as many as 220 woolly aphis.

RECOGNITION OF A PARASITIZED APHIS

The attacked aphis stops feeding and becomes quiescent soon after parasitization. Its waxy threads start dropping off within two to four days, and its colour starts darkening from pinkish to dark brown, ultimately becoming jet black. It remains fixed to the plant by a secretion (produced under stimulation of parasitization), its rostrum also remains fastened in the plant tissue. The parasite larva eats up the internal organs leaving only a hardened shell behind. Thus a parasitized aphis is devoid of white, waxy filaments, and has a hardened body which is glossy black in colour. The adult parasite comes out of the body of the host by cutting out of a neat circular hole in its hardened body-wall.

TABLE II

Number of woolly aphis parasitized by a female parasite at Kulu

No.	Experiment started on	Date of oviposition	Parasite died on	Number of individuals parasitized
1	2 June . .	4-10 June . .	11 June . .	35
2-4	,, . .	4-15 June . .	15 June . .	220
5-7	4 June . .	6-15 June . .	15 June . .	25-42
	,, . .	7-17 June . .	17 June . .	115
9-11	1 July . .	4-11 July . .	12 July . .	11-72
12	,, . .	4-12 July . .	,, . .	192
13	,, . .	4-12 July . .	,, . .	215
14	,, . .	4-12 July . .	,, . .	187
15	2 August .	5-9 August . .	10 August	13
16-17	,, .	5-10 August . .	11 August .	12-80
18	,, .	4-14 August . .	14 August .	38
19-20	,, . .	4-14 August . .	15 August .	15

RANGE OF FLIGHT

In order to study the distance which it will travel (by flying or will be carried by wind) to reach its host from the original point of introduction, the parasite was liberatred only in certain orchards in the Kulu valley. These observations show that it can cover a distance of 2½ miles.

CARE AFTER ESTABLISHMENT

In the Punjab the parasite requires constant care for the following reasons:—

(1) Kulu valley is severely infested with the notorious San Jose' Scale (***Fobesaspis perniciosus*** Comst.). The orchardists spray their gardens every winter with diesel oil emulsion to control it [Rahman, 1940]. The spray material kills the hibernating parasite grubs, with the result that in the following spring, the parasite is either absent from, or is present in very greatly reduced numbers in, the treated orchard. Fresh colonies of the parasite have to be introduced to rehabilitate it.

(2) The predators [Rahman and Khan, 1941] such as *Ballia eucharis* Muls., *Oenopia sauzeti* Muls., *Chilomenes bijugus infernalis* Muls., *Syrphus confrater* Wd., *Ancylopteryx punctata* Hog. and red mites feed indiscriminately on woolly aphis. As such they play havoc with the parasite also, particularly during April-August.

In order to protect the prarasite against these calamities, various experiments were carried out, and the following measures were found to give adequate protection :—

(1) *Against diesel oil emulsion.*—The apple twigs bearing a parasitized and healthy woolly aphis were ' planted ' in a 4 ft. ×2 ft. ×2 ft. wire-gauze cage towards the end of November and early December near a water channel. They were irrigated or watered with a gardeners' can, etc. regularly twice a week throughout winter. The parasite became active in March and quickly built up an affective population in subsequent months.

(2) *Against predators.*—The apple twigs bearing healthy and parasitized woolly aphis were ' planted ' in a 4 ft. × 2 ft. × 2 ft. wire-gauze cage in March-April. These twigs were replaced by freshly cut infested shoots after every 15 days during summer. They were irrigated or watered with a gardeners' can thrice a week during summer. The parasite bred in the cage unmolested, from where it flew out continuously and regularly, and thus maintained its field population at an effective level.

SUMMARY

Woolly aphis (*Eriosoma lanigerum* Hausm.) was introduced into the Punjab in 1909. It is at present found in the Kulu valley and the Simla hills. Its parasite—*Aphelinus mali* Hald.—was successfully introduced and established in the Kulu valley in August 1937.

A. mali has been reported from about 22 different species of aphids from elsewhere, but in the Punjab, it has been found to be a specific parasite of woolly aphis.

On an average the adult parasite lives for seven to eight days. It is active during March-November when it passes through 15 generations. Its life-cycle is completed in 20-33 days in March-June and 11-18 days in June-October. It hibernates as a grub in the body of its host during mid-November to mid-February.

The parasite attacks wingless adults and 4th stage nymphs commonly, and 3rd stage nymphs rarely ; it never attacks winged adults and 1st and 2nd stage nymphs. When its activity is at peak, one female may parasitize as many as 220 woolly aphis. The parasitized aphis loses its white, waxy threads and becomes jet-black in colour ; it remains fixed to the plant. The adult parasite can cover a distance of 2½ miles to reach its host.

After the parasite is established, it requires protection from winter sprays and from predators. The methods to achieve this protection are described.

REFERENCES

Greenslade, R. M. (1936). *Imp. Bur. Fr. Production, Tec. Ser., No.* **8**

Rahman, Khan A. (1940,1). *Indian. Farming* **1**, 387

———————— (1940,2). *Punjab Agric. Coll. Mag.* **7**, 60

Rahman, Khan A. and Khan, A. W. (1941). *Indian. J. agric. Sci.* **11**, 265

SELECTED ARTICLE

THE WATER REQUIREMENTS OF RICE IRRIGATION

BY

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THE future will probably see in China large scale engineering works involving the irrigation of rice. In order that these may be planned to be as efficient as possible, an accurate knowledge is required of the water necessary to irrigate rice, both the total amount required and the distribution of the demand throughout the irrigation season. When rice irrigation is already practised in the region where the works are planned, the best way to secure this information is to measure over a number of years the requirements of small plots already under irrigation. Unfortunately, before construction of a project is authorized, money to carry out such studies is usually not available, and when the project is authorized, construction cannot be postponed until the data is collected. In such a case valuable data can be secured from an investigation of the irrigation requirements in similar regions. When the irrigation project is planned in a region where rice has not been previously cultivated, the only data source is that of other regions.

Since both of these conditions exist in China, it is believed that an investigation of the water requirements under as wide a range of conditions as possible should prove of value in China and in other countries where such projects may be contemplated. The following study was therefore undertaken at the University of Iowa by Messrs Cheng and Pien under the direction of Prof. E. W. Lane, as a subject for their thesis as candidates for the degree of Master of Hydraulic Engineering.

In the following pages are given a summary of the methods of analysis used and the results obtained. It is hoped that additional data on this subject may be secured in order that further studies of this type may be made and a more detailed report prepared giving the results of the entire study.

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TABLE

Summary of the rice irrigation

1	2	3	4	5	6	7	8	9	10	11
					Soil condition				Approximate date of	
Country	State or Province	Location	Period	Area (acre)	Surface soil	Subsoil	Variety of rice	Method of irrigation	First irrigation	Beginning of submergence
U. S. A.	California*	Sacramento Valley	1916—1918	355	Copay clay		Early & late	Canal	April 13 to May 22	May 19 to July 12
,,	,,	,,	,,	8,477	Willows clay adobe		,,	,,		
,,	,,	,,	,,	5,057	Willows clay		,,	,,		
,,	,,	,,	,,	2,877	Stockton clay adobe		,,	,,		
,,	,,	,,	,,	4,653	Sacramento clay		,,	,,		
,,	,,	,,	,,	267	Tehoma clay loam & clay		,,	,,		
,,	,,	,,	,,	302	Vina clay loam		,,	,,		
,,	,,	,,	,,	45	Willows loam & clay		,,	,,		
,,	,,	,,	,,	122	Willows loam		,,	,,		
,,	,,	,,	,,	51	Sam Joaquin loam		,,	,,		
,,	,,	(d) Biggs	1914—1917	71	Stockton clay adobe		,,	,,	April 15	June 9
,,	Arkansas	Arkansas County	1928—1929	1,088	Crowley silt loam	Impervious clay	Early & late	Pumping	May 20 to June 10	
,,	Taxas†	...	...	...	,,	,,		,,	May	July
,,	Louisiana†	Crowley	1917—1919	...	,,	,,	Early & late	Pumping	May	July
China	Kiangsu	Wukiang Hsien	1934—1935	...	Clay		Early		April 25 to April 30	June 1 to June 8
,,	,,	Wuchin Hsien	1928—1935	5,380	Impervious clay		Late	Pumping	May 5-10	June 10
,,	Kwangtung ‡	Canton	1927—1929	...	Clay loam		Early		April 20	May 5
,,	,, ‡	,,	,,	...	,,		Late		July 21	Aug. 5
Indo-China	Annam§	Thank Hoa	...	111,195	Clay			Canal	June 11	July 1
Java	Tangerang‖	...	...	...	Clay				Nov.	
(i) India	Madras¶	Maruteru	1937	495	Clay			Canal	June 26	July 11

(a) Average value of 1916 records in Sacramento Valley. Bull. No. 279, Agriculture Experiment Station, University of California.

(b) Humidity, wind velocity, and temperature are the mean value and the rainfall is the average total value, from June to October, for the 5-year period from 1914 to 1918 at Sacramento Cal.

(c) Evaporation is the average total from April 16 to Sept. 30 for 11-year period, from 1926 to 1936, at Davis, California.

(d) E. I. Adams Rice Field near Biggs is also in Sacramento Valley.

(e) Weight per bushel of rice is 44·05 lbs. which is the average value in Texas. Varieties of Rice for 'Texas' Bull. No. 485, Texas Agriculture Experiment Station.

(f) The climatological data except rainfall are the records observed at the Rice Branch Experiment Station.

I

data in various countries

12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Irrigation	Average length of irrigation season			Average net depth of water used				Climatological conditions during irrigation season						
Date of water turned off (day)	Prior to sub-merg-ence (day)	Period of sub-merg-ence (day)	Total (day)	Prior to sub-merg-ence (in.)	During sub-merg-ence (in.)	Total depth applied (in.)	Yield of rough rice per acre (lb.)	Average seasonal rainfall (in.)	Av-erage season-al evapo-ration (in.)	Average seasonal humidity per cent	Average seasonal wind velocity (mil./hr.)	Monthly temperature Max. (°F.)	Min. (°F.)	Mean (°F.)
Sept. 27 to Oct. 30			159	9·85 to 26·80		47·50	(a) 2,940	(b) 1·51	(c) 49·28	(b) 56	(b) 7·7			(b) 70
			154			50·60								
			168			61·00								
			157			61·60								
			167			68·60								
			173			97·50								
			153			97·50								
			155			80·20								
			170			112·60								
			174			140·50								
Sept. 30	55	114	169	13·20	41·20	54·40	4,600	2·77	38·84		4·4	111	28	
Aug. 20 to Sept. 20			90-105		29·85		(e) 2,458	11·25	(f) 31·37	(f) 80·9	(f) 2·6	(f) 87·6	(f) 64·2	(f) 75·9
Sept.						31—37		(g) 18·00	21·35	82·8	3·6	89·7	70·5	80·1
Sept.	15—40	55—92	90-120		28·04		2,000	(h) 19·35	23·00		1·8			80
Aug. 18 to Aug. 23	23	77	100		35·90			19·55	19·36	84				81·1
Sept. 20	33	102	135			38·00		21·94	27·00					
July 28	15	84	99	5·12	19·55	24·67		16·40						81·4
Nov. 3	15	91	106	5·12	26·00	31·12		13·80						80
Nov. 30	20	153	175			51·33		29·51	23·77					
Mar.	49	84	133	15·68	28·33	44·01		47·70	23·55	84				80
Nov. 27	15	139	154	7·86	51·79	59·65		29·00	35·82			86·8	74·8	80·8

(g) Climatological data are the average value between May 15 to Sept. 15.

(h) All the climatological data are average values or average total values from June to September, for the 3-year period from 1917 to 1919.

(i) The data were supplied by H. T. Wang, a Chinese Government engineer with irrigation experience in India.

*The daily range of temperature in State of California is about 40°F. Trouble of water grass.

†Duty of water estimated by Prof. W. B. Gregory not including the waste for Texas and Louisiana.

‡Seepage loss is low due to high under ground water table.

§Data for October season.

‖Data for wet season.

¶First crop paddy.

SUMMARY OF OBSERVED DATA ON WATER REQUIREMENTS

The first step in this study was the collection of all available information on the water required by growing rice, and the meteorological and other conditions under which these quantities were required. The localities from which the data were obtained are as follows :

(1) Sacramento Valley, State of California, U. S. A.
(2) Arkansas County, State of Arkansas, U. S. A.
(3) State of Louisiana, U. S. A.
(4) State of Texas, U. S. A.
(5) Wukiang Hsien and Wuchin Hsien, Kiangsu Province, China
(6) Canton, Kwangtung Province, China
(7) Thank-Hoa, Annam, Indo-China
(8) Tangerang Werken, Java
(9) Maruteru, Madras Province, India

At Wukiang, Wuchin, Tangerang, Thank-Hoa and Maruteru, not only was the total requirement of water in the rice field determined, but also the amount of water used during each stage of the plant growth. In Louisiana, Wukiang, Canton, and Annam, the loss from field evaporation, transpiration, and seepage was also determined. The results of experiments and estimations of the duty of water for rice in various localities are summarized in Table I, which also gives data on the classification of soil, variety of rice, and average climatological conditions.

A study of Table I shows a wide range in the amount of water used, varying from 24·67 inches to 140·50 inches due to the difference in environmental conditions. The chief causes of this wide variation may be summarized as follows :

(1) In the State of California, U. S. A., the net duty of water varie from 47·5 inches to 140·5 inches, undoubtedly due to the variation in the nature of the soil, since all of the data in California were observed in the same district of the Sacramento Valley, there being no material difference in the climatological conditions.

(2) In the rice sections of the states of Arkansas, Texas and Louisiana the water requirements for rice irrigation are nearly equal, averaging about thirty inches. The reasons for this condition are the similar soils, subsoils, and climatological conditions.

(3) Comparing the data observed in California with that from Arkansas, Texas, and Louisiana, it is found that more water is required in the California district than in the latter, probably due principally to the difference in climate. In the state of California, the total evaporation during irrigation season is about 49 inches, and the mean monthly temperature is 70° F. In the three southern states the total evaporation during irrigation season is about 22 inches, and the mean monthly temperature is about 80° F. The evaporation in California is much higher, in spite of the lower temperature, because of the lower humidity and higher wind velocity.

(4) In the Kwangtung experiments, the water requirements for both the early and late rice were smaller than those in Kiangsu. The reason seems to be the low transpiration loss in Kwangtung. The reason for the low transpiration loss cannot be determined because of the lack of the necessary climatological data. Another reason for the lower requirements for early rice in the Kwangtung experiment, as compared with those in Kiangsu, is the lower seepage loss in the former experiments resulting from a high water table, and higher seepage in the latter because the experiments were carried on in a new field.

(5) In Indo-China the data presented are only the estimates used in design of the rice irrigation projects, and these estimated values may be higher than the actual amount of water required since the evaporation loss was assumed equal to the free water surface evaporation.

(6) Because of the higher evaporation and longer irrigation season in India, the observed value is very large.

ANALYSIS OF OBSERVED DATA AND DEVELOPMENT OF METHOD OF DETERMINING WATER REQUIREMENTS OF RICE

The four major divisions into which the duty of water for rice irrigation may be divided are as follows :

(1) the evaporation from the water surface of the rice field,
(2) the transpiration of water by the rice plants,
(3) the seepage of water out of the rice field through the ground,
(4) the initial application of water necessary to prepare the land for cultivation and to supply the water required for the first submergence.

The first three of these divisions will be handled as a group and classified as losses during the submergence period. The proportion of each of the three losses during the period varies widely with the soil texture, variety of rice, method of irrigation, length of irrigation season, difference of climate, and other conditions of irrigation practice. The proportions of the total water used in the three divisions in the various localities are shown in Table II.

TABLE II

Consumption of irrigation water in rice fields during period of submergence

Country	Locality	Loss by evaporation		Loss by transpiration		Loss by seepage		Total	
		in.	Per cent	in.	Per cent	in.	Per cent	in.	Per cent
U. S. A. .	Louisiana . .	10·10	36·00	16·38	58·50	1·56	5·50	28·04	100
China . .	Wukiang . .	8·64	23·70	15·48	43·20	11·88	33·10	35·90	100
China . .	Canton . . .	9·28	47·50	6·85	35·00	3·42	17·50	19·55	100
China . .	Canton . . .	13·00	50·00	6·63	25·50	6·37	24·50	26·00	100
Indo-China .	Annam . . .	...	...	19·70	...	...	...	...	...
	,, . . .	...	...	16·42	...	...	...	...	...

The distribution of the loss among the three items is not uniform during the whole irrigation season. In general, the field evaporation is greater in the first part of the irrigation season and smaller in the latter part, while the loss from transpiration is smaller in the first of the season and greater during the latter. Fig. 1 was prepared to illustrate this fact, using the data of Pansan Rice Field Experiment Station, Kiangsu, China, in 1934 and 1935. These losses are discussed in detail in the following paragraphs.

(1) Loss by field evaporation

The soil in the rice field is submerged in water to a depth of several inches during most of the growing season. The majority of the factors affecting field evaporation, such as temperature, wind velocity, and relative humidity, are the same as those affecting evaporation from a free water surface. The only other important factor influencing field evaporation is the effect of the stage of growth of the rice plants. When this factor is considered, the loss by evaporation from a free water surface will give a general indication of the loss from the field.

A summary of observed data showing the relation between field evaporation and evaporation from a free water surface is given in Table III.

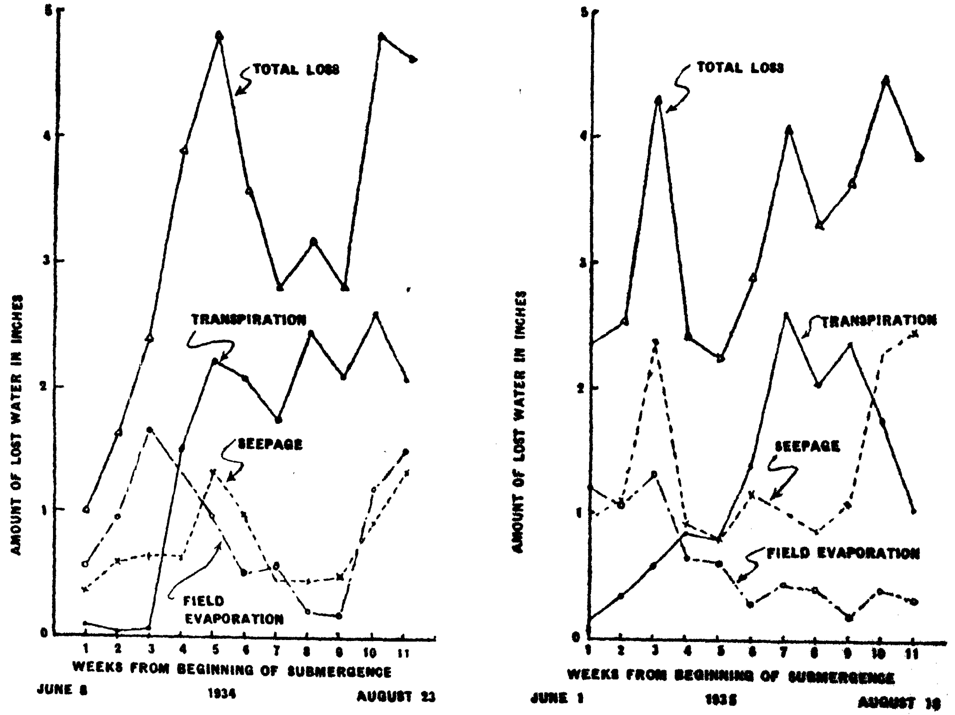

FIG. 1. Relation of lost water from evaporation, transpiration and seepage during period of submergence, Wukiang, China

TABLE III

Evaporation in rice field during period of submergence

Location	Field evaporation (inches)	Evaporation from a free water surface (inches)	Remarks
Louisiana, U. S. A.	10·10	15·72	
Wukiang, China	8·54	12·80	Early rice
Canton, China	9·28	11·05	Early rice
Canton, China	13·00	17·34	Late rice

By plotting these data on logarithmic paper, a relation between the field evaporation and the evaporation from a free water surface was found which may be expressed approximately by the following equation :

$$E_f = 1 \cdot 8E^{2/3}$$

where E_f = total field evaporation in inches during the period of submergence.
E = total evaporation in inches from a free water surface during the same period.

The data on total evaporation from a free water surface which have been collected during the submergence season vary from 11 to 35 inches. To obtain reasonable results in using this equation, only evaporation records which come within these limits should be used.

For determining the distribution of this loss during the irrigation season, further study is required. The only data showing the effect of the stage of growth of rice plants on the field evaporation is that from the Pansan Rice Field Experiment Station, Wukiang, China, shown in Fig. 2.

From this curve, it will be seen that during the first part of the submergence period the cumulative field evaporation is nearly equal to that from the free water surface, and during the remainder of the submergence period, the cumulative field evaporation varies approximately as a straight line, but is less than the water surface evaporation. During the first part of the season, the field is open water and has practically the same evaporation as a free water surface ; but after about 40 per cent of the season has elapsed, the shading effect of the growing plants becomes appreciable, and the rate of evaporation is materially reduced.

In computing the distribution of field evaporation loss throughout the season for any locality, the evaporation for the first 40 per cent of the period is considered equal to the free water surface evaporation, and the distribution for the remaining 60 per cent is assumed to be constant at the rate which will bring the total to the value $1 \cdot 8E^{2/3}$. When this method was applied to the records where water surface evaporation records were available, values were found from which a generalized diagram (Fig. 3) was prepared showing the ratio of the accumulated field evaporation to the accumulated water surface evaporation throughout the submergence season. These ratios differed somewhat depending upon the total water surface evaporation. This diagram enables an estimate to be made of the amount necessary to supply the evaporation requirements of rice at any time during the submergence period, if the evaporation data are available, by subtracting the accumulated value at the beginning of the time interval from that at the end of the interval.

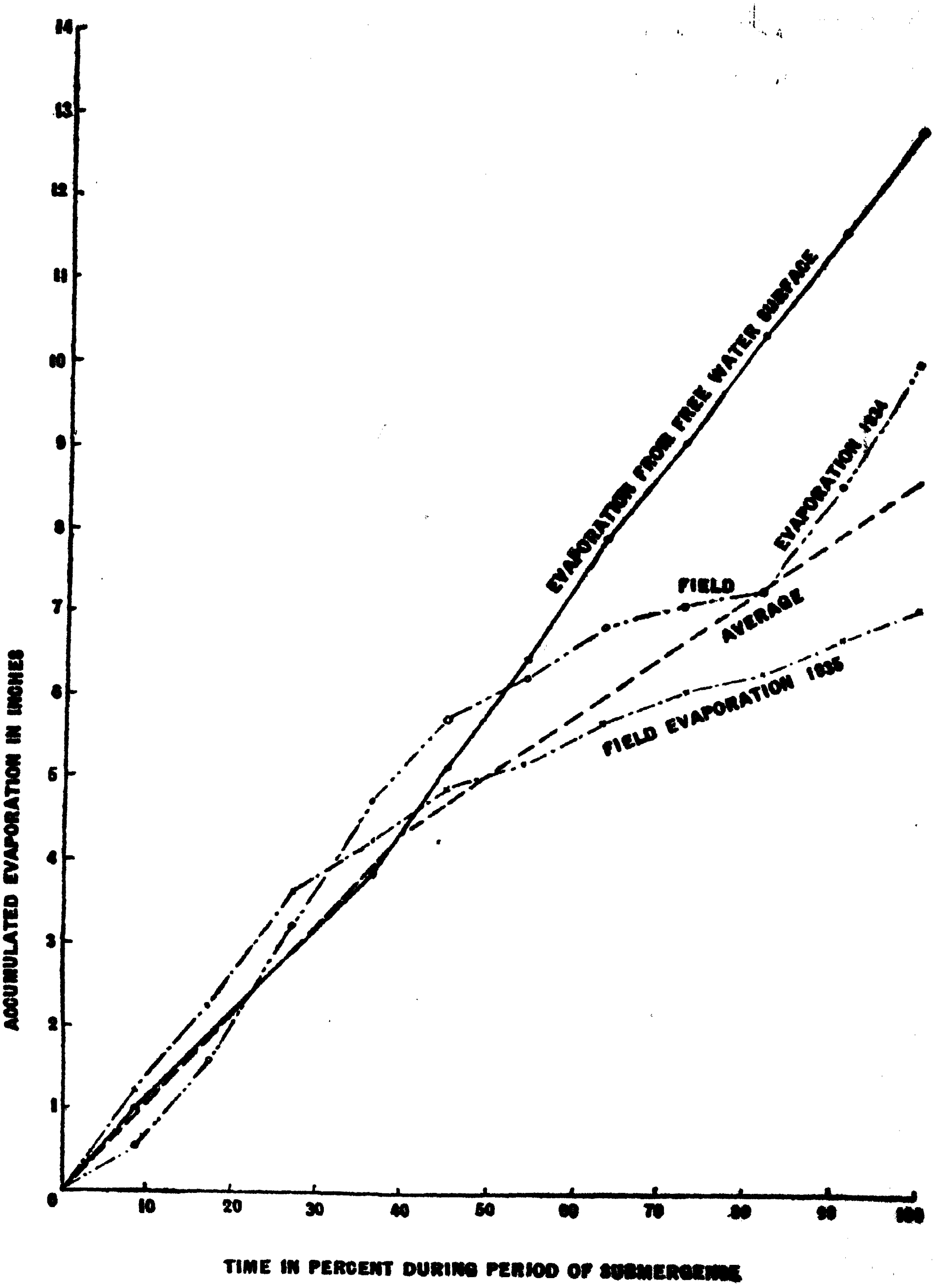

FIG. 2. Mass curve of field evaporation during period of submergence, Wukiang, China

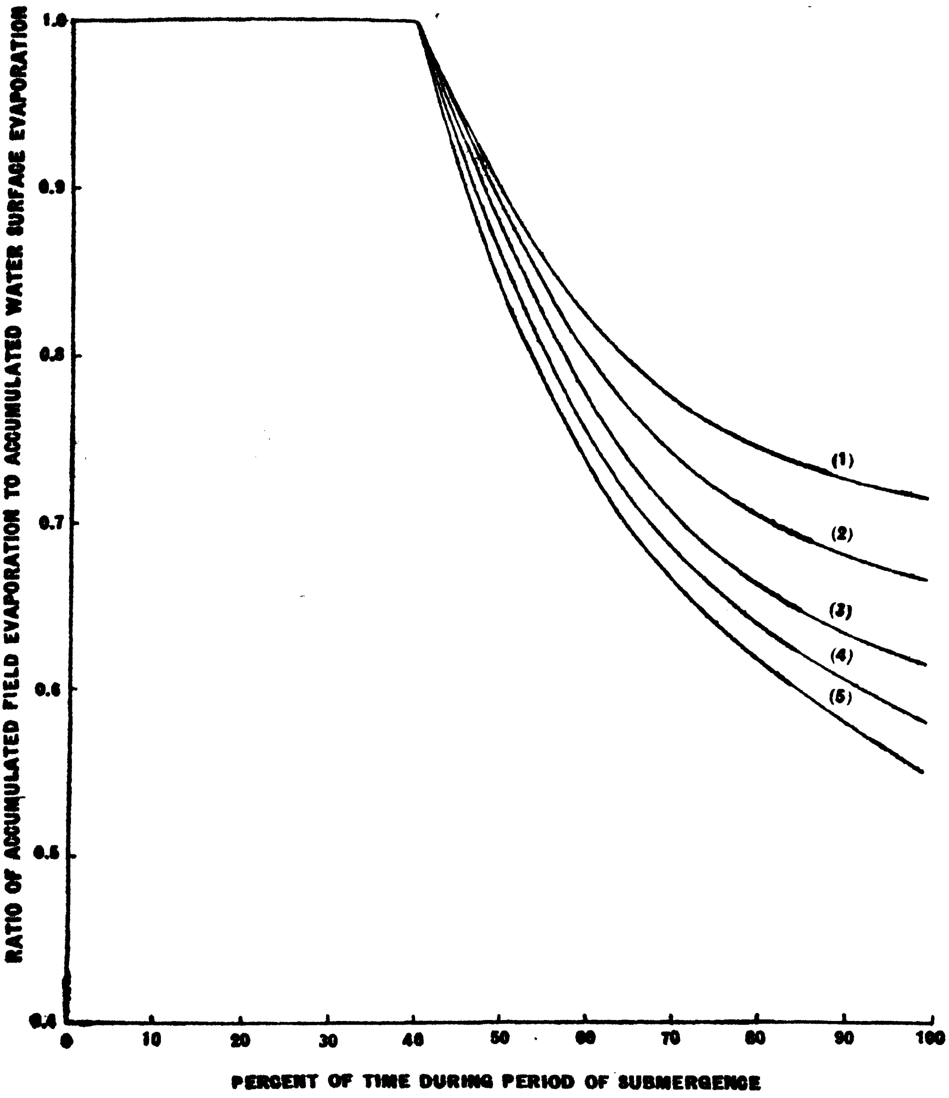

FIG. 3. Various ratios of accumulated field evaporation to accumulated water surface evaporation

(1) For water surface evaporation during period of submergence 15 inches
(2) ,, ,, ,, ,, ,, ,, 20 ,,
(3) ,, ,, ,, ,, ,, ,, 25 ,,
(4) ,, ,, ,, ,, ,, ,, 30 ,,
(5) ,, ,, ,, ,, ,, ,, 35 ,,

(2) Loss by transpiration

The main factors affecting transpiration in rice fields are much the same as those affecting evaporation from a free water surface. In Table IV are collected all available data on evaporation and transpiration during the submergence period. The ratio of transpiration to evaporation has been computed also.

Table IV

Total transpiration and evaporation during submergence season

Experiment station	Submergence season	Transpiration during submergence (in.)	Evaporation during submergence (in.)	Ratio of transpiration to evaporation	Remarks
Wukiang .	June 1 to Aug. 16	15·48	12·79	1·21	Mean value from 1934-1935
Louisiana .	July 1 to Sept. 30	16·62	15·72	1·03	Mean value from 1910-1917
Texas	July 1 to Sept. 30	16·50	15·53	1·06	Mean value estimated by Prof. W. B. Gregory
Annam .	July 1 to Nov. 30 (Oct. season)	19·68	20·08	0·83	Estimated value for computation of duty of water

These data were plotted on logarithmic paper with evaporation from the free water surface against the transpiration, and the equation $P=6\cdot6E^{1/3}$ was derived in which

P=total amount of transpiration of rice plants during submergence period, in inches.

E=total amount of evaporation from free water surface during submergence period, in inches.

The distribution of the transpiration and the field evaporation throughout the submergence season was also determined. Data were available from Annam, Louisiana, and Wukiang giving both the transpiration and the evaporation losses throughout the season. The variation of these is shown in Fig. 4. Using these data and the relation $P=6\cdot6E^{1/3}$ for the total transpiration at the end of the season, a generalized diagram (Fig. 5) was prepared showing the ratio of the accumulated transpiration to the accumulated water surface evaporation during the submergence period for various values of total water surface evaporation. From this diagram it is possible to determine the rate of water use for transpiration for any short period by finding the accumulated total at the beginning and end of the period.

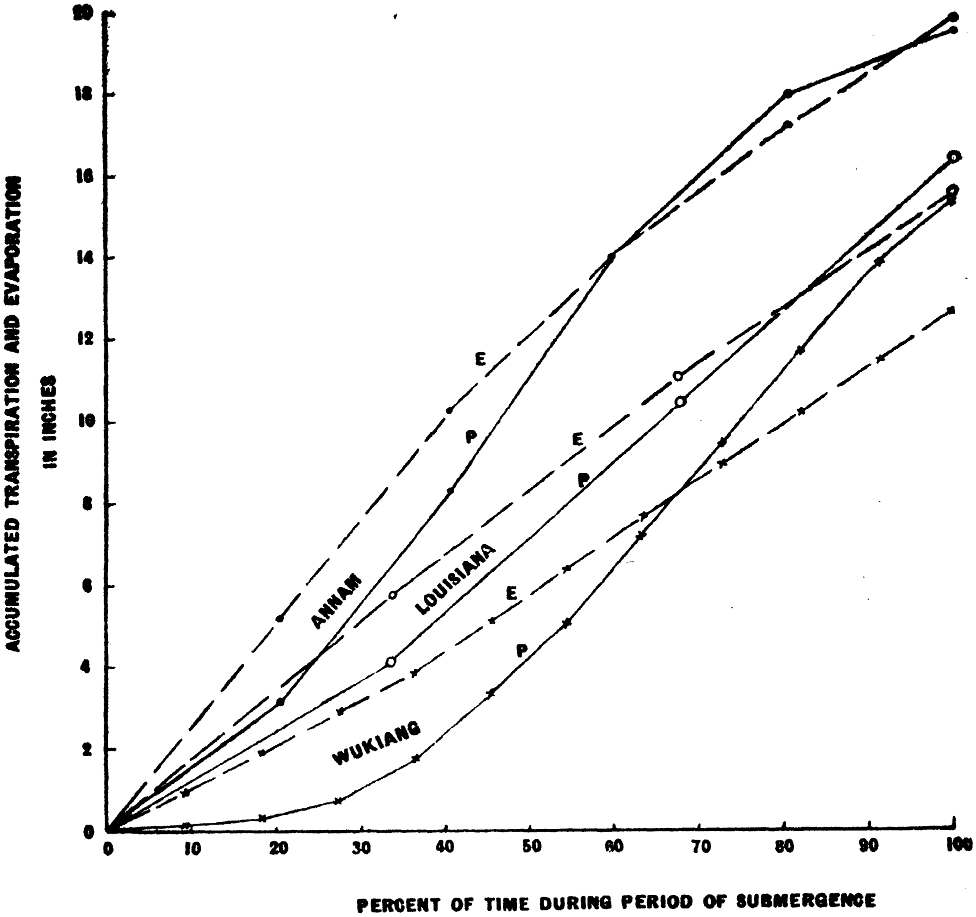

FIG. 4. Mass curve of transpiration and water surface evaporation during period of submergence at Annam, Louisiana and Wukiang

E = Water surface evaporation ; P = Transpiration

(3) LOSS BY SEEPAGE

The most important factor affecting the amount of seepage is the character of the soil. Other factors, such as temperature, depth of water in rice field, ground water table, and age of the rice field, also affect the amount of percolation.

It is very difficult to measure directly the actual amount of percolation. In general, the field observations of percolation are made by subtracting the other losses from the total loss and charging the remainder to percolation. Some observed data obtained in this manner are given in Table V.

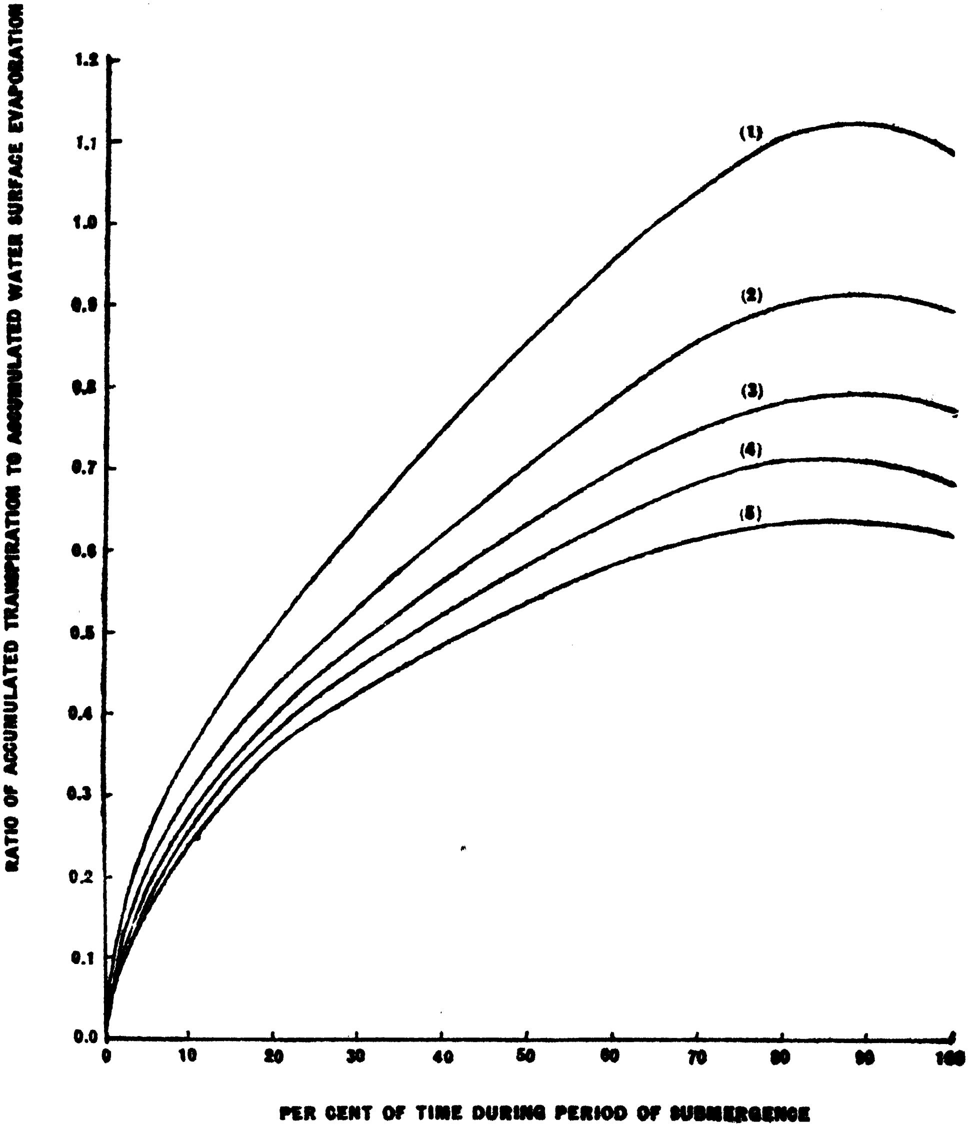

Fig. 5. Various ratios of accumulated transpiration to accumulated water surface evaporation

(1) For water surface evaporation during period of submergence 15 inches
(2) " " " " " " 20 "
(3) " " " " " " 25 "
(4) " " " " " " 30 "
(5) " " " " " " 35 "

TABLE V

Observed data of seepage loss

Location	Soil class	Length of season (days)	Total seepage (in.)	Daily loss of seepage (in.)	Remarks
Louisiana, U. S. A.	Silt loam over impervious clay	92		0·017	Average value of 4″ to 6″ depth of water during submergence
Wukiang, China	Clay . .	77	11·88	0·154	New rice field
Canton, China	Clay loam .	84	3·42	0·041	Underground water table is high
Canton, China	,, ,, .	91	6·37	0·071	Underground water table is high

The surface soil in the state of Louisiana is Crowley silt loam, while the subsurface soil is an impervious clay. The daily seepage loss of 0·017 inch observed in this region may be considered as a minimum value for the impervious clay subsoil. In the state of California, some data are available on the duty of water, which give the classification of soil,and are very valuable for the comparison of seepage losses. Assuming the daily loss of seepage for Willows clay adobe to be 0·017* inch, the same as in the state of Louisiana, and the seepage loss to be uniformly distributed during the whole irrigation season, the daily loss by seepage for the other classes of soil is estimated in Table VI.

TABLE VI

Estimated daily loss of seepage for various classes of soil in state of California

Soil class	Length of whole irrigation season (days)	Total net depth of water applied (in.)	Estimated loss by seepage (in.)	Daily loss by seepage (in.)	Average daily loss by seepage (in.)	
Willows clay adobe .	154	50·60	2·62	0·017	Clay	0·076
Willows clay . .	168	61·00	13·02	0·077		
Stockton clay adobe	157	61·60	13·62	0·087		
Sacramento clay .	167	68·60	20·62	0·123		
Willows clay loam .	155	80·20	32·22	0·208	Clay loam	0·273
Tehama clay loam .	172	97·50	49·52	0·288		
Vina clay loam .	153	97·50	49·52	0·323		
Willow loam . .	170	112·60	64·62	0·380	Loam	0·456
San Joaquin loam .	174	140·50	92·52	0·532		

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* **Later studies show that this is probably too low and should be about 0·020.**

For general application, the range of daily loss by seepage in rice field for the different soils is summarized in Table VII.

TABLE VII

Daily loss of seepage for various ordinary classes of soil

Soil class	Daily loss of seepage (in.)	Average daily loss of seepage (in.)
Impervious clay	0 —0·050	0·025
Clay adobe	0·050—0·100	0·075
Pervious clay	0·100—0·150	0·125
Clay loam	0·150—0·350	0·250
Loam	0·350—0·550	0·450

Only from the state of Louisiana were data available on the mechanical analysis of surface soil and subsoil and permeability tests of the soil. Based on the results of seepage losses found in Tables VI and VII, a tentative chart (Fig. 6) was prepared for the determination of daily seepage for different soils at a mean temperature of 70° F. The percolation values obtained from this chart should be increased by about $1\frac{1}{4}$ per cent per degree Fahrenheit for average temperatures above 70° and correspondingly decreased for values below. The chart is based upon comparatively little data and therefore it is given tentatively with the hope that more data may become available by means of which the chart can be revised.

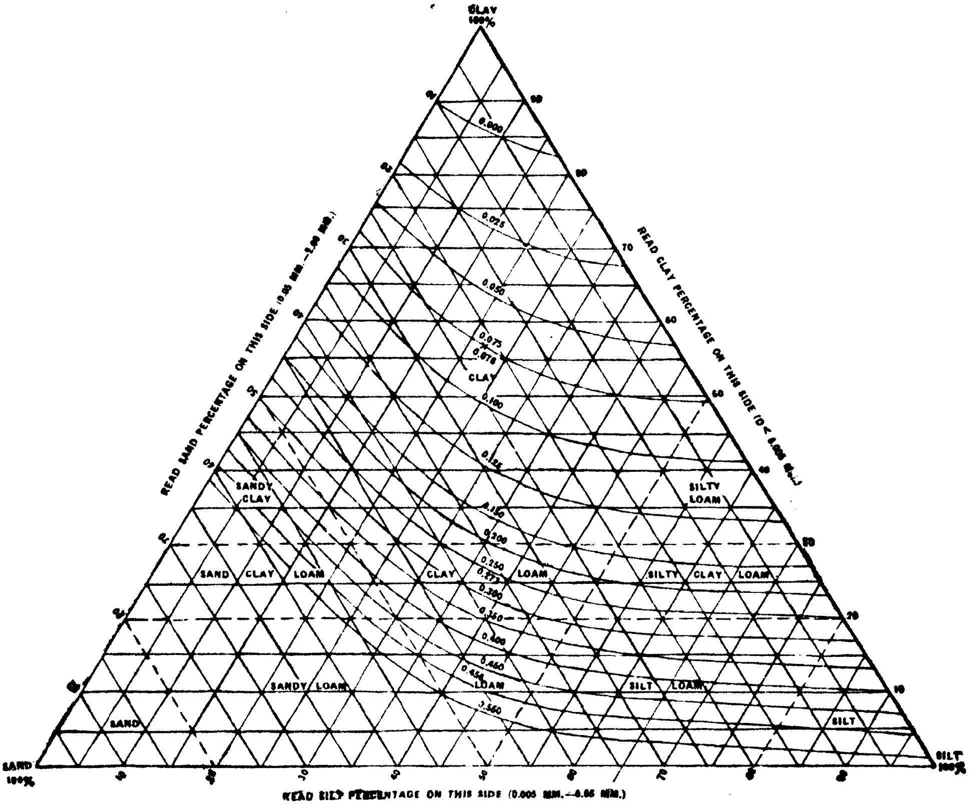
(4) WATER REQUIRED BEFORE SUBMERGENCE

There are two seeding methods which are generally used in various countries : (1) the broadcast method, generally used in the United States ; and (2) the transplanting method, generally used in Asia.

In the Sacramento Valley, California, where the broadcast method was used, the amount of water required in 1916 prior to submergence was determined for different soils. The total amount of water used before submergence minus the uniform seepage loss during the period for the particular type of soil (assumed at the same rate as during the submergence period) gave about 4 inches as the average required for initial submergence.

In the experiment made by the College of Agriculture, National Chunsan University, Canton, China, where the transplanting method was used, the water required was 5·17 in. for the 15 days before submergence. The average daily seepage was 0·059 inch. The difference between the total amount required and the total seepage before submergence was nearly 4 inches.

Since the water used before submergence in both cases may be represented by the same factors, it is thought that the water required before submergence may be estimated by the formula, sl_1+4, in which s is the daily seepage in inches and l_1 is the length of the period before submergence.



F G. 6. Tentative chart for the determination of daily seepage (in.) for different kinds of soil at 70°F.

(5) EMPIRICAL FORMULA FOR ESTIMATION OF NET DUTY OF WATER FOR RICE

The consumption of water in the rice field, the field evaporation, transpiration, seepage, and the water required before submergence, have been investigated separately. Combining the four factors, the total net duty of water for rice (excluding the losses beyond the rice field) throughout the irrigation season is $D=6\cdot 6E^{1/3}+1\cdot 8E^{2/3})sL+4$. In order to simplify the equation the values of the sum of $6\cdot 6E^{1/3}$ and $1\cdot 8E^{2/3}$ were plotted against E on logarithmic paper and the following formula obtained: $6\cdot 6E^{2/3}+1\cdot 8E^{2/3}=7\ E^{1/2}$.A more simple formula is therefore suggested, which is

$$D=7E^{1/2}+sL+4$$

in which

D=the total net duty of water in inches for rice.

E=total evaporation in inches from a free water surface during submergence period.

s=average daily seepage in inches in rice field during entire irrigation season.

L=total days during irrigation season.

In any locality where the length of irrigation season, the total evaporation during the submergence season, and the soil characteristics are known, the total approximate net duty of water required for rice may be found from the equation given.

If there are no records of evaporation in the locality, the total evaporation may be estimated from hydrological data by evaporation formulas such as that of Meyer*,

$$E=15\ (V-u)\ (1+\frac{W}{10})$$

in which

E=evaporation in inches depth per 30-day month

V=maximum vapor pressure in inches of mercury corresponding to monthly mean air temperature observed by Weather Bureau at nearby stations.

u=actual pressure of vapor in air based upon Weather Bureau determinations of monthly mean air temperature and relative humidity at nearby stations.

W=monthly mean wind velocity in miles per hour about 30 ft. above general level of surrounding country or roofs of city buildings.

In order to determine the probable accuracy of the results obtained with this formula, a comparison has been made between the observed values and those computed by the formula for all cases in which the data were available. The results of this comparison are shown in Table VIII. From the table it may be seen that only in the case of Canton, China, was the difference between computed and observed values large. The discrepancy seems to be largely in the item of transpiration, the observed transpiration at Canton for no evident reason being considerably less than that at any other place covered by the records.

(6) GRAPH FOR ESTIMATION OF DISTRIBUTION OF NET DUTY OF WATER

In the design of canals for an irrigation project, the maximum amount of water required during any interval of time is more important than the average amount of water required during the whole irrigation season. The empirical formula previously developed can only be used to estimate the total net duty of water for the whole irrigation season. Therefore, a study of the distribution of irrigation water during the season is necessary.

The most important factor affecting the distribution of irrigation water is the stage of growth of the rice plant, which affects field evaporation and transpiration as shown in Figs. 3 and 5. Combining Figs. 3 and 5, the distribution graph for field evaporation and transpiration is given in Fig. 7.

The distribution of the water required throughout the season can be estimated from the distribution graph (Fig. 7) by: (1) assuming that the seepage losses are uniformly distributed during the whole irrigation season and obtaining the amount of daily seepage loss from Fig. 6, (2) adding the amount of water for initial flooding, (3) estimating the amount of water required for transpiration and evaporation.

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* *Engineering News-Record*, Aug. 6, 1936, *Graphical aid in the solution of Meyers' evaporation formula* by A. S. Levens

ORIGINAL ARTICLES

THE DESCRIPTION OF CROP-PLANT CHARACTERS AND THEIR RANGES OF VARIATION

BY

B. P. PAL

AND

MEMBERS OF A SPECIAL SUB-COMMITTEE

WITH A FOREWORD

BY

W. BURNS

FOREWORD

FOLLOWING up discussions in the Advisory Board of the Imperial Council of Agricultural Research for India in 1936-37, two committees were formed, one for cotton and one for rice, whose labours resulted in the description of the characters of these crops and their range of variation*. These attempts to prepare schedules to standardize the description of crops have received appreciation from various quarters.

Regarding 'Variability of Indian Cottons' an American cotton geneticist wrote :

'We must admit that the publication will be of value to us and we shall be using it as a sort of manual or guide in our introduction work where we are attempting to get together an extensive collection of cottons and to classify them taxonomically and morphologically and to make studies regarding their behaviour under our conditions. Thus, we are very grateful to you for the many excellent ideas suggested in your Journal article.'

Mr Hutchinson, who was the moving spirit in the preparation of the cotton publication, expressed the hope that this appreciation would encourage the Council to proceed with similar studies on India's other important crops.

The Imperial Council decided to attempt a similar publication on wheat and, for this purpose, appointed a committee consisting of the following members :

Dr B. P. Pal (Chairman), Imperial Economic Botanist ;
Mr K. Ramiah, Geneticist, Institute of Plant Industry, Indore ;
Rai Bahadur Dr K. C. Mehta, Professor of Botany, Agra College, Agra ;
Rao Sahib Ch. Ram Dhan Singh, Cerealist, Punjab ;
Dr B. L. Sethi, Economic Botanist for Cotton and Rabi Cereals, United Provinces ;
Rao Sahib K. I. Thadani, Director of Agriculture, Sind.

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*Hutchinson, J. B. and Ramiah, K. (1938) : 'The description of crop-plant characters and their ranges of variation. I. The variability of Indian cottons. II. Variability in rice.' *Ind. J. Agric. Sci.*, Vol. 8, pp. 567-616

The basis for this publication was a detailed note prepared and circulated by Dr B. P. Pal and later on revised by him in the light of suggestions received from members of the Committee. The Committee met in Simla in June 1940.

The Appendix on 'Quality in Wheat' was kindly prepared by Rao Sahib Ch. Ram Dhan Singh.

The drawings and photographs were prepared at the Imperial Agricultural Research Institute by Mr K. M. Dhar and Mr S. C. Ghosal respectively, under Dr B. P. Pal's supervision.

In the collection and checking of data for the preparation of the note, Dr Pal was assisted by Mr S. Z. Hasanain, Wheat Breeding Assistant, and by Messrs Harbhajan Singh and H. C. Mirchandani, post-graduate students, and in the examination of wheat material by Mr Habibur Rahman Khan, Fieldman.

It is hoped that this publication will be as useful as its two predecessors and will afford a convenient system for the description of wheat varieties in such a way that easy comparison of types emanating from different areas and breeders will be possible.

W. BURNS
Agricultural Commissioner
with the Government of India

September 13, 1940

III. THE VARIABILITY OF INDIAN WHEATS

(Received for publication on 23 July 1940)

(With Plates XXI-XXX)

MATERIAL TO BE DESCRIBED

THE wheat material to be described may be said, broadly speaking, to be of two kinds, one composed of varieties of commercial importance (these may be old varieties or improved varieties evolved by the departments of agriculture in India) and the other consisting of the large numbers of varieties and hybrid derivatives which are maintained at the main breeding stations for purposes of hybridization or for exchange with breeders in other centres. While the former is likely to be small in number, the latter, as pointed out by Hutchinson and Ramiah [1938], is likely to include hundreds or even thousands of pure lines, and they have recommended that, whereas the descriptions of varieties of commercial importance ' should be as elaborate and as detailed as possible, the description of the type collections will have to be simpler and should be considered mainly from the genetical point of view '.

In view of the general similarity of the wheat material to be described to the rice material dealt with by Hutchinson and Ramiah, it is not necessary to discuss the former in great detail. The recommendations of the authors relating to strains obtained from other provinces, and in particular the desirability of retaining the original names or numbers in such cases apply also to wheat.

SPECIES OF WHEAT CULTIVATED IN INDIA

Five species of *Triticum* are cultivated in India, namely :—

T. dicoccum Schübl.

T. durum Desf.

T. turgidum L.

T. sphaerococcum Perc.

T. vulgare Host

In order to appreciate the position of the Indian wheat species it is necessary to consider briefly their relation to the wheats of the world. As is not uncommon with taxonomic problems, there has been considerable divergence of views regarding the classification of wheats. Accounts of the history of classification have been given by Percival [1921], Clark and Bayles [1935], etc.

The consensus of modern opinion appears to agree on the recognition of the following groups and species. The distinguishing characteristics of these species are well known, and it has not been considered necessary to describe them here.

Group I (Einkorn group ;	$2n = 14$ chromosomes)
Wild :	*T. aegilopoides* Bal.
	T. Thaoudar Reut.
Cultivated :	*T. monococcum* L.

Group II (Emmer group; $2n = 28$ chromosomes)
Wild : *T. dicoccoides* Körn.
T. Timopheevi Zhuk.*
Cultivated : *T. dicoccum* Schübl.
T. durum Desf.
T. persicum Vav.
T. orientale Perc.
T. pyramidale Perc.
T. Polonicum L.
T. turgidum L.

Group III (Bread or *vulgare* group; $2n = 42$ chromosomes)
Wild : Nil
Cultivated : *T. vulgare* Host
T. compactum Host
T. sphaerococcum Perc.
T. Spelta L.
T. Macha Dek. et Menab.
T. Vavilovi Jakubz.

The grouping of the wheat species into three groups is a natural one based not merely on the chromosome numbers but is supported by serological studies [Zade, 1914] and studies of susceptibility of the species to certain disease-causing fungi [Vavilov. 1914]. Sax [1921] found that the size of the pollen grain is likewise different in the three groups. The species within any one group are fertile *inter se* but show varying degrees of sterility when intercrossed.

It will be observed that of the five species of wheat cultivated in India, the first three belong to the Emmer group with the chromosome number $2n = 28$ and the remaining two to the Bread group with the chromosome number $2n = 42$. In general the wheats belonging to the former group possess a higher degree of resistance to some of the more important diseases of wheat than those of the second group. Thus *T. dicoccum* includes some of the most rust-resistant wheats known, *T. persicum* is immune or nearly immune to attack by mildew and *T. Timopheevi* is reported to be highly resistant to all fungous diseases. The transference of the genes for disease-resistance from wheats of the Emmer group to those of the Bread group by breeding is, however, not simple, because of the sterility which is often encountered when such crosses are made. Even when the sterility is not complete, the subsequent segregation of characters may be complex and irregular, rendering difficult the achievement of the combinations desired. The task, however, is not an insuperable one, for some striking successes have been already obtained, for example, the production of the highly rust-resistant variety, Hope, from a cross between the well-known *vulgare* variety, Marquis, and Yaroslav Emmer.

T. monococcum

T. monococcum, the only cultivated member of the first or Einkorn group, is not represented in India. It is also reputed to be highly resistant to diseases.

Notes on the distribution of the five species are given below.

T. dicoccum

The largest proportion of this species is grown as an irrigated crop in Bombay. It is also cultivated to a small extent in Hyderabad (Deccan),

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* *T. Timopheevi* is placed by some authors separately in a fourth group

Mysore, Madras and the Central Provinces. The common trade name almost everywhere in South India is *khapli*. In Madras it is also called *samba*, while in Hyderabad the common trade description is *jod gahu*.

T. durum

Durum or macaroni wheats are met with in all the wheat-growing regions of India and commercially this is, next to *T. vulgare*, the most important species. The most extensive areas of cultivation are in the Central Provinces, Bombay, Central India and Rajputana, and Hyderabad (Deccan).

In the trade the wheats of this species are designated by a large number of trade names including *bansi, bakshi, jalalia, malvi, kathia, haura, wadanak*, etc.

T. turgidum

While, according to Howard and Howard [1909], undoubted Rivet wheats have been found in India in Baluchistan only, varieties of this species are to be found occasionally in Central India. These are not of commercial importance.

T. sphaerococcum

This species, according to Percival [1921], is endemic to India and to Iran. According to Howard and Howard [1909], dwarf wheats belonging to *T. compactum* are found in the south-west of the Punjab and, to a smaller extent, in the Central Provinces and the United Provinces. Percival, however, believes that the *compactum* wheats referred to by Howard and Howard belong to *T. sphaerococcum* and that *T. compactum* is not found in India. In a recent paper, Ellerton [1939] states that *T. sphaerococcum* is found in Sind and eastern Baluchistan also.

T. vulgare

This is by far the most important wheat species and embraces the greater portion of the wheats grown in India. The trade names include *sharbati*, choice white Karachi, *pissi*, *dudhi*, etc.

The several species of wheat are subdivided into smaller groups or varieties, these being founded, as a rule, upon a number of morphological differences of the ears and grain. The classification of varieties will be considered in the next section.

THE PROBLEM OF VARIETIES

While the classification of wheats into species is fairly easy and there is quite general agreement on this point, the further classification of these species into sub-groups or varieties presents a problem of considerable complexity. In *T. vulgare* and, to a lesser degree, in *T. durum*, the existing forms are so numerous and so intergrade in all their characters between one extreme and another that the formation of clearly defined groups or classes is almost impossible. Percival [1921] has suggested that the best way of dealing with such extensive material is to make a separate classification of the forms of these species cultivated in each country.

As regards the criteria for the classification of varieties a large number of classifications have been drawn up, varying in the degree of importance assigned to the various characters. These classifications are, almost without exception, based on botanical characters and are frankly artificial. Perhaps the most popular of these is that of Körnicke [1885], being extremely convenient and clearly defined for taxonomic purposes. This is based on the presence or absence of awns, colour of glumes, etc. Under this system, however, as Vavilov [1923] has pointed out, two forms which are alike in all characters save that of glume colour would be placed in two different botanical varieties, whereas forms differing very widely in a whole range of characters but agreeing in the few simple characters used as criteria would be placed in one and the same botanical variety. Hector [1936] in fact says that all such classifications should be regarded merely as ' classificatory guides '. This state of things is hardly surprising when we recall that the varieties within each cultivated wheat species interbreed freely. With the large number of characters available in the wheats and the wide range of variation within each of the characters the number of possible combinations obtainable by hybridization, etc. is almost endless. A formal botanical classification is therefore almost meaningless, and rather than the description of ' types ' themselves, the description of the more important characters with a view to establishing the range of variability available for breeding purposes is desirable. It is necessary therefore to standardize the methods of description and presentation in order that these when published may be of value to all workers on the crop.

CHARACTERS TO BE DESCRIBED

Broadly speaking, the characters to be described are of two kinds : (1) Characters, primarily of a qualitative nature, which are not greatly influenced by external factors. Vavilov [1923] has pointed out that certain of these features characterize whole groups of races and are commonly accompanied by a series of correlative features. Such characters naturally must form the first line of classification in a system which aims at the establishment of genetically akin groups. (2) Quantitative characters which are subject to fluctuation. Some of these are more easily distinguishable and vary less than others, e.g. winter and spring habit, size of grain, etc. and such differences between the forms of wheat can be readily observed by growing the material under the same conditions. Other characters, such as the degree of tillering and the consistency of the grain, fluctuate very greatly and, although of considerable economic importance, they can be used for separating forms only when grown under identical conditions for a number of consecutive seasons.

In order to obtain uniformity in the description of the characters given below it is recommended that as a general rule a sample of 25 normal plants per progeny row be taken for purposes of measurement or description. The observations should be taken over a period of three successive seasons.

A. Plant characters

1. Height of the plant

Height is an important factor and is often related to the resistance or otherwise of the variety to lodging, and to productivity. Height should be measured from the surface of the ground to the tip of the ear, omitting, however, the awns in the case of awned varieties. Three classes may be distinguished, tall, medium and dwarf. Class limits for these classes should be fixed by the economic botanists in the several wheat-growing tracts and will be understood as applying only to the tract from which the wheats are described. It is not considered desirable to suggest one set of class limits for the whole of India as, obviously, height will be greatly influenced by the locality and the time of sowing.

2. *Tillering*

Varieties may be classified into those with little tillering and those with much tillering. The average number of tillers at the maximum tillering phase and the average number of ear-bearing tillers should also be given. This character can be used with safety only when the varieties to be compared are grown under identical conditions and over a period of not less than three years.

3. *Maturity*

The heading date is more convenient to use than the ripening date and the number of days from sowing to complete emergence of the ear should be noted. On the basis of this the wheat varieties may be classified as early, mid-season and late. It is obvious that the maturity is influenced by the time of sowing and will also vary according to the locality. This therefore is another character which must be used with much caution.

B. Ear and grain characters

Ear characters

1. *Shape of the ear.*—Wheat ears can be classified in respect of shape into four classes : fusiform, oblong, clavate and elliptical (Plate XXI). In common wheats the shapes are determined from a face view of the spikelets, and in club, *durum* and *turgidum* wheats from an edge view of the spikelets.

2. *Length of the ear.*—Ears may be described as short, mid-long and long. The average length of the ear measured from the ring at the base of the rachis to the tip of the uppermost spikelet (excluding the awn) should be given. The average total number of spikelets should also be stated.

3. *Density of the ear.*—Ears may be described as lax, mid-dense or dense. Various methods have been suggested for determining the ear density and the most convenient one consists in determining the number of millimetres occupied by 10 internodes of the rachis measured in the middle of the ear. It does not appear to be desirable to fix any rigid limits for the three classes recognized, as there is considerable variation depending upon the locality and season.

4. *Position of the ear at maturity.*—Erect, inclined and drooping ears may be distinguished.

5. *Other characters.*—Colour of the anthers—yellow or purple.

Awn characters

1. *Presence or absence of awns.*—This character has been used by almost all botanists from Linnaeus onwards as the first in order of importance in distinguishing varieties of wheat. Wheats may be entirely beardless, fully bearded or they may possess short awns of varying length ranging from small

tips to the glumes to what may be termed the half-bearded condition. In *T. vulgare* the awns seldom, if ever, exceed 10 cm. in length ; in *T. durum* and *T. turgidum*, however, they may be much longer. Vavilov [1923] has pointed out that hooded forms also occur. They have, however, not been recorded from India.

For purposes of description, wheats may be conveniently divided into five groups : beardless, short-tipped (awnlets not exceeding 5 mm. in length), long-tipped (awnlets 5 to 40 mm. in length), half bearded and full bearded (Plate XXII).

2. *Colour of the awns.*—White, red or black.

This character is easily identified in good seasons but the development of colour varies from year to year and in certain seasons may be entirely absent. The awn colour should be noted before the crop is fully ripe, as in some cases the colour fades at maturity (Plate XXIII).

3. *Arrangement of the awns.*—Awns may be adpressed to the ear, or spreading (Plate XXIV).

4. *Character of the awns.*—Awns may be (*a*) persistent or deciduous, (*b*) coarse and brittle or slender and tough.

Glume characters

1. *Covering of the glumes.*—Glabrous (smooth), sparsely pubescent or densely pubescent (velvety) (Plate XXV).

While presence of pubescence is usually easily recognized, the degree of pubescence varies in different varieties. In some the hairs are much longer and more numerous than in others. *Durum* wheats are generally very densely felted and the hairs are long, whereas the pubescent glumes of the common and dwarf wheats are generally sparsely covered with short hairs.

2. *Colour of the glumes.*—Grades 1 to 9 (Plate XXVI).

The colour of the glumes is usually a shade of yellow or reddish brown. The former are usually described as white, and the latter as red or brown. A few varieties have black glumes or are tinged or striped with black. Glume colours other than these are also found, in some of the lesser-known species.

The depth and tone of the colour varies between different varieties and like awn-colour is influenced by seasonal factors. Unlike awn colour, it should be noted when the ear is ripe.

In some cases the margin is more deeply coloured than the rest of the glume. These should be noted.

3. *Size of the glumes.*—Glume lengths may be described as short, mid-long and long and are illustrated in Plate XXVII, fig. 1. The width of the glumes may be similarly described (Plate XXVII, fig. 2).

4. *Shape of the glume shoulder* (*Plate XXVII, fig. 3*).—The shape of the shoulder—wanting, oblique, rounded, square, elevated or apiculate—is a useful character for determining varieties. Both as regards size and shape of the glumes, the description applies to the middle spikelets of the ear and not to those at the tip or the base which differ widely from the typical spikelets of the ear.

It is unnecessary to point out that in estimating these characters it is desirable to take a number of ears for each variety and to examine a number of glumes in each ear.

5. *Size of the glume beak.*—(*a*) Width. The width of the beak may be described as narrow, mid-wide and wide (Plate XXVIII, fig. 2). (*b*) Length. As Clark and Bayles [1935] have pointed out, the length of the beak is variable, especially in awned varieties. In most awned wheats the length increases from the base of the ear to its apex, the range of difference varying with the variety. Following Vavilov [1923], beak length may be described as very short (up to 1 mm.), short (1 to 3 mm.), long (3 to 7 mm.) and very long (over 7 mm.). For this purpose the average maximum length measured from the shoulder of the glume upward should be taken. Variations in beak length are illustrated in Plate XXVIII, fig. 1.

6. *Shape of the glume beak* (Plate XXVIII, fig. 3).—The apex of the beak varies considerably in shape and may be described as obtuse, acute, or acuminate.

7. *Tenacity of glumes.*—Persistent or deciduous.

The glumes of most varieties are firmly attached to the rachis and are persistent. In some varieties of *T. vulgare,* however, the glumes are easily deciduous, causing the ears to shatter.

Grain characters—

1. *Colour of grain.*—Grades 1 to 3 (Plate XXIX).

Hayes, Bailey, Arny and Olson [1917] state that 'the visual appearance of wheat which is commonly termed colour is due to the joint effect of two factors : first, the presence or absence of a brownish red or orange-yellow pigment in the bran layer, and second, the physical condition of the endosperm cells. The latter may be corneous or starchy, depending upon the density of the cell contents or the relative amount of space occupied by air cavities or vacuoles '. The grain colour has been used by Körnicke and Werner and others as one of the leading taxonomic characters of wheat.

Howard and Howard [1909] regard the wheat kernel as being either white or red, the tint of colour of both classes varying a good deal. The red wheats vary from dark brownish-red to light red, while the white wheats include yellowish and amber tints. They also state that the particular tone of colour depends partly on the consistency of the grain and, since consistency varies in the same variety, both from year to year in the same locality and also in different localities in the same year, it is not safe to use tone or tint of colour as a distinguishing character. Clark and Bayles [1935] have also grouped kernels of all wheat varieties into two classes—white and red. For Indian wheats it appears desirable to distinguish the amber group from the white and red classes, in view of its commercial importance. All the three colour grades illustrated are found in *vulgare* wheats, whereas in *durum* wheats only grades 2 and 3 are generally found.

2. *Length of the grain.*—Short, mid-long or long.

As suggested by Clark and Bayles [1935], kernels which are less than 6 mm. in length may be classed as short, those ranging from 6 to 8 mm. as mid-long, and those exceeding 8 mm. as long.

In making measurements only normal grains from the middle spikelets should be used. Ten grains should be taken.

3. *Texture of the grain.*—The texture of the kernel is an important character as most wheat is marketed in commercial classes based largely on

texture. For purposes of classification, however, the character is a very variable one and to determine it satisfactorily the wheat forms to be compared must be grown under similar conditions for a period of not less than three years.

It is convenient to recognize three classes, viz. soft, semi-hard and hard. Hard wheats are often liable to mottling and the extent of this should be noted.

4. *Shape of the grain.*—The outline of the kernel of *T. vulgare* as viewed from the dorsal surface may be described as ovate, elliptical or oval (Plate XXX, fig. 1). Modifications of these shapes may be indicated by describing the kernels as narrowly or broadly ovate, elliptical or oval, as the case may be.

Both in *T. durum* and in *T. dicoccum* the grains are rather narrow and tapering towards both ends. The typical grain of *T. turgidum* is broad and plump with a high dorsal arch or hump behind the embryo. The grain of *T. sphaerococcum* is very characteristic, being shorter and rounder than that of other wheats.

It is important to take only normally developed typical grains from the middle spikelets, and the material to be compared should have been grown under identical conditions.

The tip or brush end of the kernel may be tapering, rounded or truncated.

5. *Width of the crease.*—The crease may be narrow or wide.

6. *Depth of the crease.*—The crease may be shallow or deep, and pitted or non-pitted.

7. *Shape of the cheeks.*—Cheek shapes may be rounded or angular (Plate XXX, fig. 2).

C. *Vegetative characters*

1. *Colour of the young shoot*

This is usually green but in some cases is purple because of the presence of anthocyanin.

2. *Early growth habit*

All types occur from prostrate to very erect. It is convenient to distinguish three classes : erect, intermediate or semi-erect, and spreading.

3. *Presence or absence of the ligule*

Vavilov [1923] has shown that in some wheats the ligule is absent and that it is a useful character for purposes of classification.

4. *Colour of the auricles*

These may be purple or colourless.

5. *Presence or absence of hairs on the auricles*

This is an easily distinguishable character.

6. *Character of the leaf-sheath*

This may be glabrous or pubescent.

7. *Pubescence of the leaf-blade*

The leaf-blade may be glabrous or pubescent. In the latter class, different grades can be distinguished depending upon the kinds of hairs present and their distribution.

8. Other leaf characters

Leaf-blades of wheat varieties may differ in respect of their colour, size, and in the angle which they make with the culm during the successive periods of growth. The terminal leaf in particular is quite erect in some varieties and drooping at various angles in others : in some it is curled or twisted. These characters, however, are difficult to estimate or are clearly apparent only for a brief period. For this reason they are not proposed to be used. Any very obvious differences, such as very broad or very narrow leaves, should, however, be noted.

9. Glaucousness of the plant

Plants may be glaucous or non-glaucous.

10. Colour of the stem

The stem colour may be green or purple. This should be determined about 10 days before ripening.

11. Thickness of the straw

Varieties may be grouped into : (*a*) those with thick straw, and (*b*) those with thin straw.

12. Solidity of the straw

The straw in the upper part of the culm below the ear may be solid or hollow.

D. Other characters

1. Yield

While it is the most important character from the point of view of the grower, yield does not readily lend itself for use in classification. The results of properly replicated and randomised trials carried out over a series of years, however, form useful measures of the comparative productivity and should be noted.

2. Quality

Quality in wheat is difficult to define. A note on this subject appears as Appendix II. The bushel weight, 1000-kernel weight and protein content should be given as explained therein. As already mentioned, grain colour and texture should also be described.

3. Disease-resistance

Resistance and susceptibility to specific diseases should be determined under conditions favourable for the maximum development of the disease and such that all the varieties are equally exposed to the disease. When physiologic races of the disease-causing organism exist, this fact should be taken into account in planning the tests. The results of such tests where known should be noted in the varietal descriptions.

4. Resistance to cold, heat, drought, lodging, etc.

The resistance or susceptibility of varieties to various adverse conditions should be mentioned whenever this information is available.

REFERENCES

Clark, J. A. and Bayles, B. B. (1935). *Tech. Bull. U. S. Dep. Agric.* **459**

Ellerton, S. (1939). *J. Genet.* **38**, 307-24

Hayes, H. K.; Bailey, C. H.; Arny, A. C. and Olson, P. J. (1917). *J. Amer. Soc. Agron.* **9**, 281-4

Hector, J. M. (1936). *Introduction to the botany of field crops*: Central News Agency, Johannesburg; 478 pp.

Howard, A. and Howard, G. L. C. (1909). *Wheat in India*: Thacker Spink, Calcutta; 288 pp.

Hutchinson, J. B. and Ramiah, K. (1938). *Indian J. agric. Sci.* **8**, 567-616

Körnicke, F. (1885). *Arten und Varietaten des Getreides*: Paul Parey, Berlin; 470 pp.

Percival, J. (1921). *The wheat plant*: Duckworth, London; 463 pp.

Sax, K. (1921). *Genetics* **6**, 399-416

Vavilov, N. I. (1914). *J. Genet.* **4**, 49-65

——————— (1923). *Bull. Appl. Bot.* (*Leningrad*) **13**, 149-257 [English summary by Imperial Bureau of Plant Breeding and Genetics—'A contribution to the classification of soft wheat, *Triticum vulgare* Vill.']

Zade (1914). *Zeits. f. Pflanzenz.* **2**, 101-51

APPENDIX I

(*a*) *Specimen schedule*

1. Experiment Station
2. Nature of soil
3. Average rainfall (average of 5 years)
    - (*a*) For the whole year
    - (*b*) For the wheat season (months to be stated)
4. Temperature range (average of 5 years)
    - (*a*) For the whole year
    - (*b*) For the wheat season
5. Humidity range (average of 5 years)
    - (*a*) For the whole year
    - (*b*) For the wheat season
6. Nature and amount of manure applied
7. Date of sowing
8. Seed rate
9. Average spacing
10. Number of irrigations, with intervals
11. Layout

(b) *Ear and grain characters*

STRAIN		EAR CHARACTERS					AWN CHARACTERS				GLUME CHARACTERS							GRAIN CHARACTERS										OTHER CHARACTERS	REMARKS
Old name or number	New name or number	Shape of the ear	Length of the ear	Density of the ear	Number of spikelets	Position of the ear at maturity	Presence or absence of awns and degree of awning	Awn colour	Arrangement of the awns	Character of the awns	Glume hairiness	Glume colour	Glume size	Glume shoulder shape	Beak size	Beak shape	Tenacity of the glumes	Grain colour	Grain length	Grain texture	Grain shape	Crease width	Crease depth	Cheek shape	Bushel weight	1000-kernel weight	Protein content	Anther colour	

(c) *Vegetative and other characters*

STRAIN		LEAF AND STEM CHARACTERS											OTHER CHARACTERS							REMARKS
Old name or number	New name or number	Colour of the young shoot	Early growth habit	Presence or absence of the ligule	Auricle colour	Auricle hairiness	Leaf-sheath hairiness	Leaf-blade hairiness	Other leaf characters	Stem colour	Straw thickness	Solidity of the straw	Plant glaucousness	Plant height in cm.	Number of tillers per plant	Maturity (number of days from sowing to heading)	Yield per plant in gm.	Disease-resistance	Resistance to adverse conditions	

APPENDIX II

Quality in wheat

Quality in crops, and for the matter of that in wheat, is a highly ambiguous term. The layman often thinks that it is associated with nutritive value. But this is not really the case, as in practice quality is generally tantamount to commercial desirability and therefore is closely related to the uses to which the products of a particular crop are generally put. Wheat, for example, is mostly consumed in the form of loaves (leavened bread) or, as in India and most other Asiatic countries, in the form of *chapatis* (unleavened pancakes), and quality in wheat has therefore to be mainly judged from these two standpoints. Such a judgment, however, is not easy to make, as in either case quality is a composite, complex character, being the resultant of a number of physiological characteristics, which are highly subject to the influence of environment and are, therefore, very variable. To appraise these characteristics correctly, it is necessary to collect data for a number of years, at least three, by comparing the varietal material under identical conditions of growth and culture. There is no doubt that the final and most reliable proof of the milling and baking qualities of wheats can only be obtained by properly planned, actual milling and baking (including *chapati*-making) tests, but as such work requires the assistance of modern milling and baking laboratories, which, with the solitary exception of the one recently started at Lyallpur, do not exist in India at present, it is not possible to subject to such tests locally the numerous types and cultures which the Indian plant breeders may have to handle, even if sufficient quantities of the seed of the latter were available. Therefore, the Indian breeding material under study can only be tested and characterized with reference to the most important characteristics which go to make up baking quality and which can be assessed with simple appliances available in an ordinary research institute and without the aid of an elaborate cereal technological laboratory.

The loaf-making quality of a wheat variety depends in the main on the rate of gas production and on gas retention when the dough made from its flour is subjected to yeast fermentation and later to baking in the oven. The gassing power in turn depends on diastatic activity, but, as the influence of variety on diastatic activity is only secondary and, as hardly any breeder will have the necessary facilities and the necessary time for making such determinations, it would simply be a counsel of perfection to lay down that this should be attempted. The appraisement of this characteristic may therefore ordinarily be left out. The power of gas retention, on the other hand, is mainly a varietal trait and depends on the quantity and quality of gluten, which in turn are generally a direct function of the protein of a wheat. It is important therefore that a breeder should obtain information on the protein content and quantity and quality of gluten of his wheat breeding material so as to be able to select the most desirable sorts and to discard types that do not come up to the mark in these respects. In order to base the work of selection and rejection on still more secure foundations, he must also collect data on some other points which, while easily determinable, may with advantage supplement the information collected by him with regard to protein and gluten. It is therefore felt that determinations in respect of the following characteristics would supply as sound a basis for the selecting and discarding of types as is possible with the facilities ordinarily available to a wheat breeder.

Texture.—Wheats may be hard, semi-hard or soft, irrespective of whether they are white or red. Generally soft wheats have a low and hard ones a high baking quality. It is easy to distinguish between soft and hard wheats from their appearance as soft ones when cut across present a mealy or starchy appearance, whereas hard ones when so treated look translucent or glassy. Hard wheats are often liable to mottling, i.e. to the presence of soft patches in their endosperm on a hard background, which defect is a serious one. Although there is hardly any variety which under adverse conditions would escape mottling, yet varieties do differ among themselves with regard to their liability to mottling, and freedom from mottling is a point of quality of irresistible appeal to all concerned in the handling of wheat. Therefore, in describing the grain texture of wheats, not only should it be stated that they are hard or soft, but also the extent of mottling in them should be noted, taking for comparison wheat Punjab C 591 as the standard, which is much less liable to mottling than most other Indian wheats.

Bushel and 1000-kernel weights.—As the milling quality of a wheat depends on the yield of flour which it gives and as the yield of flour is correlated with the bushel and 1000-kernel weights, these should be given whenever possible. Bushel weights, which even with small samples can easily be determined by the use of a chondrometer, should be taken on a cleaned wheat basis and under three classes, viz. low, less than 60 lb.; medium, 60 to 62 lb.; and high, above 62 lb., per bushel. Corresponding limits for the 1000-kernel weight in the case of bread wheats, may be taken to be somewhat as follows :—

(1) Low, less than 30 gm.
(2) Medium, 30 to 35 gm.
(3) High, over 35 gm.

Protein content.—This is a better indicator of strength in bread wheats than any other one chemical measure and, when combined with the determination of the quality of gluten which the protein of a wheat yields, gives a very good indication of the baking quality of a wheat. A high protein content is not only a general indicator of high baking quality, but usually also an indicator of good water-absorbing capacity and of high food value, and for this reason may also be of value in assessing the *chapati*-making properties of a wheat. Three following protein classes may tentatively be adopted for classifying Indian wheat :—

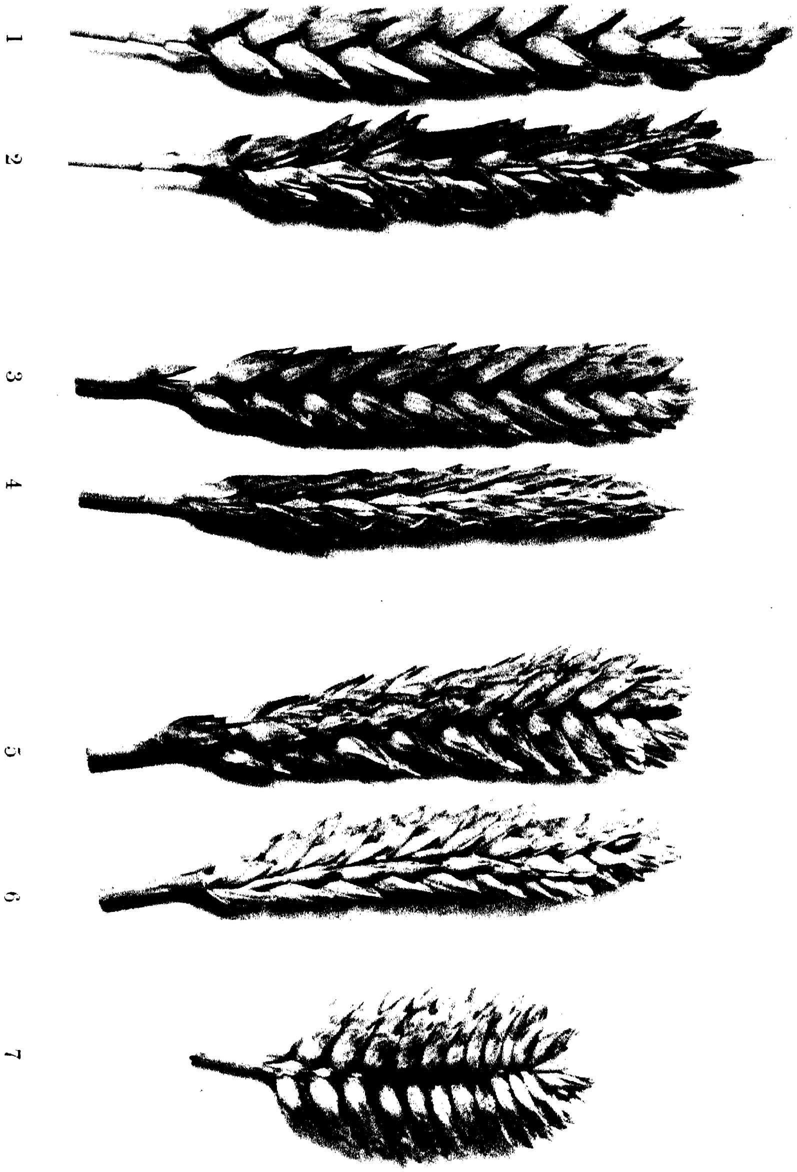
(1) Low protein content, less than 9 per cent
(2) Medium protein content, 9 to 12 per cent
(3) High protein content, above 12 per cent

Gluten.—Whenever possible, the weight of wet and dried gluten yielded by 10 gm. of fine wheat-meal should be given and also the ratio between wet and dry gluten, which supplies a rough comparative measure of the water-absorbing capacity of the flour. The quality of the gluten should also be stated. It may be short, i.e. incapable of much stretching and may therefore break off in a sharp manner when stretched. Such gluten is of poor quality. On the other hand, it may be smooth and possess good elasticity, extensibility and spring—all signs of good quality.

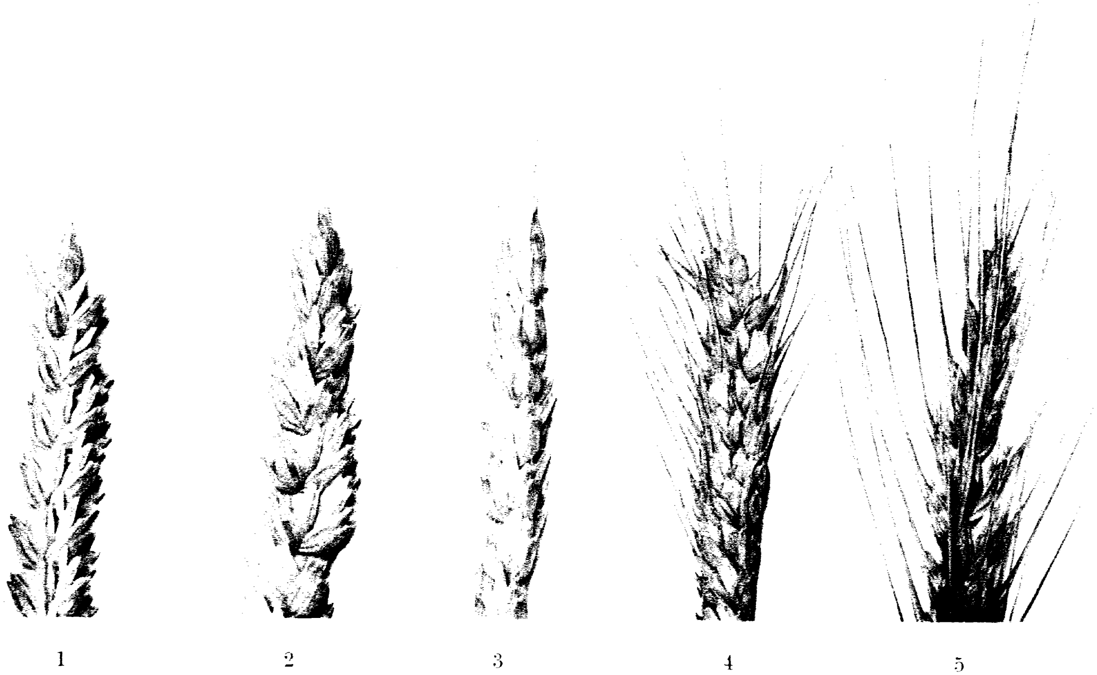
Wheat-meal-fermentation-time tests.—A very useful micro-test of quality is furnished by what is known as the wheat-meal-fermentation-time test which consists in immersing a dough ball, made of 10 gm. of wheat-meal and 5·5 c.c. of 10 per cent yeast suspension in 80 c.c. of distilled water (contained in a low-form beaker) maintained at 80°F. The time-interval in minutes between the immersion of the dough ball and when it starts to disintegrate serves as a measure of gluten quality. The longer this time-interval, generally better the quality of gluten or the baking power of wheat under study.

However, in making this test, as the time-interval also depends on the quality and activity of the yeast employed, it would appear that, instead of laying down any limits for the various classes, it would be advisable to take Pusa 4 or Punjab 8B as the standard of highest excellence and present the results by stating how far the wheat under consideration falls short of either of these standards.

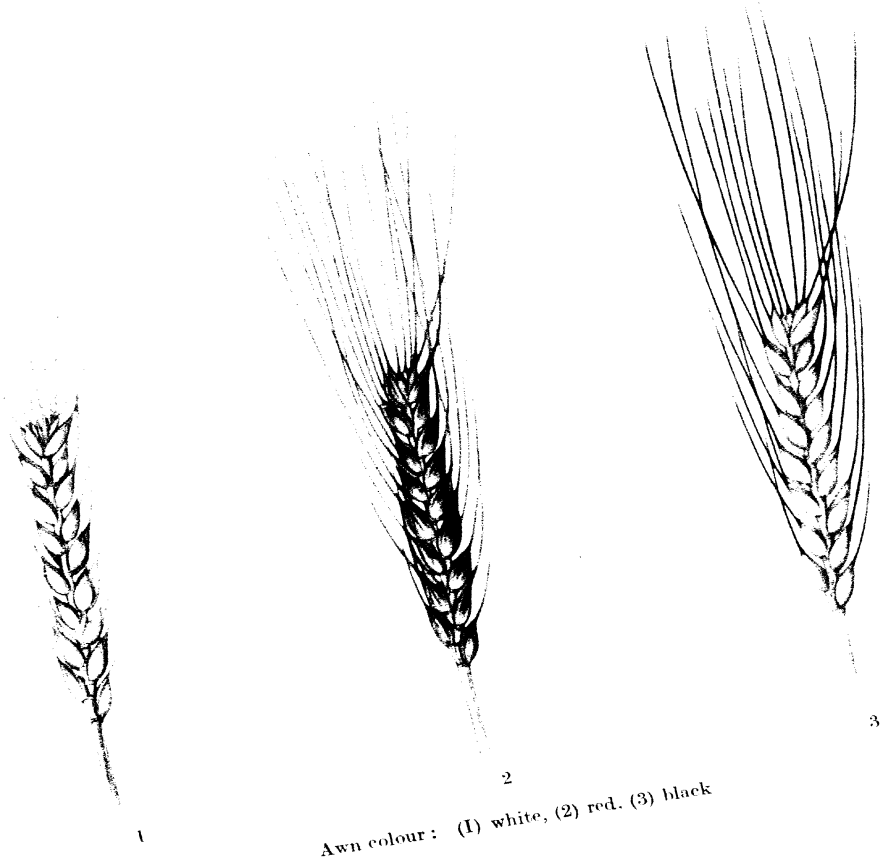
Baking tests.—As already stated, it would hardly be possible for a breeder to have the quality of his wheat varietal material tested by extensive actual baking tests, but wherever this may be found possible, Pusa 4 or Pusa 111, on account of their high baking quality, should be employed as standards for judging the loaf-making quality. Similarly, for testing the *chapati*-making properties, Punjab C591, on account of its excellence in this respect, should be taken as the yardstick.



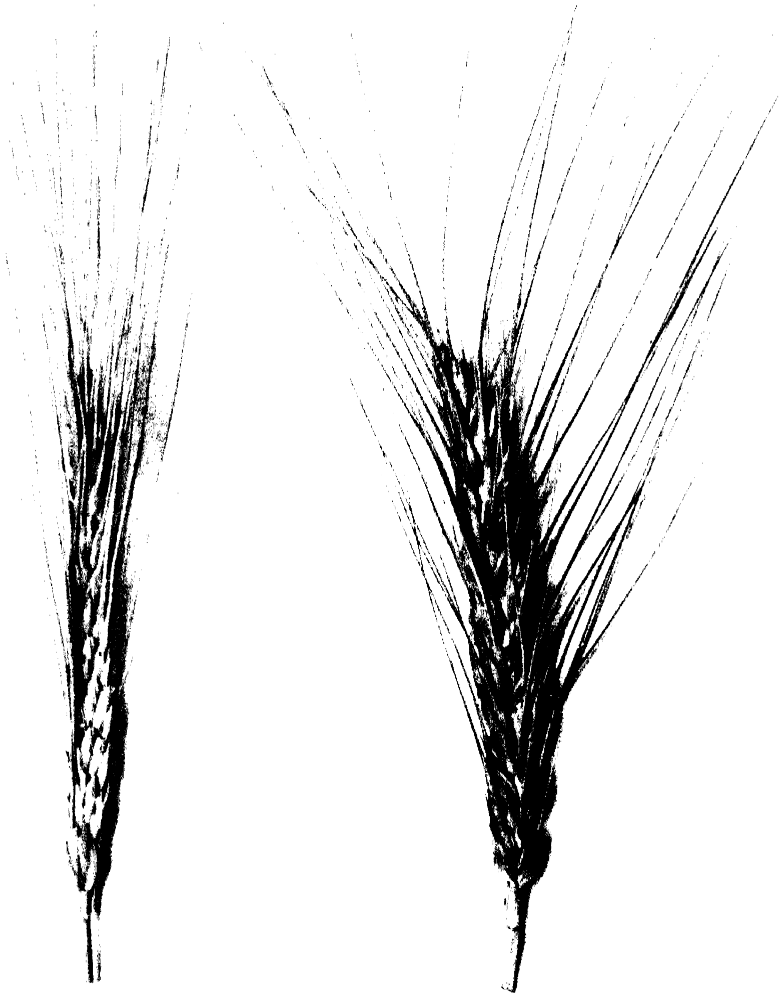
Shape of ears : (1,2) fusiform ; (3,4) oblong ; (5,6) clavate ; (7) elliptical



Awns : (1) awnless. (2) short-tipped. (3) long-tipped. (4) half-bearded. (5) full-bearded

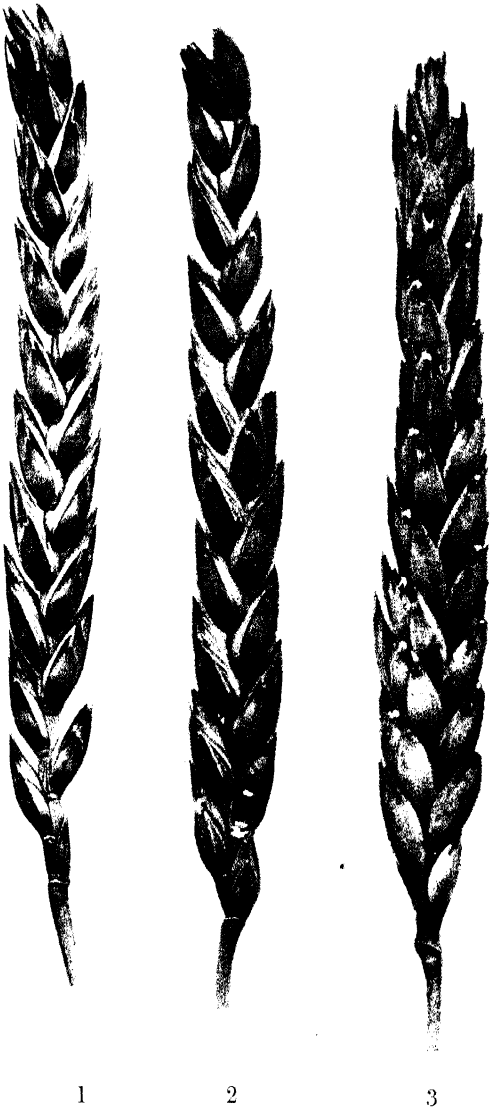


Awn colour : (I) white, (2) red. (3) black

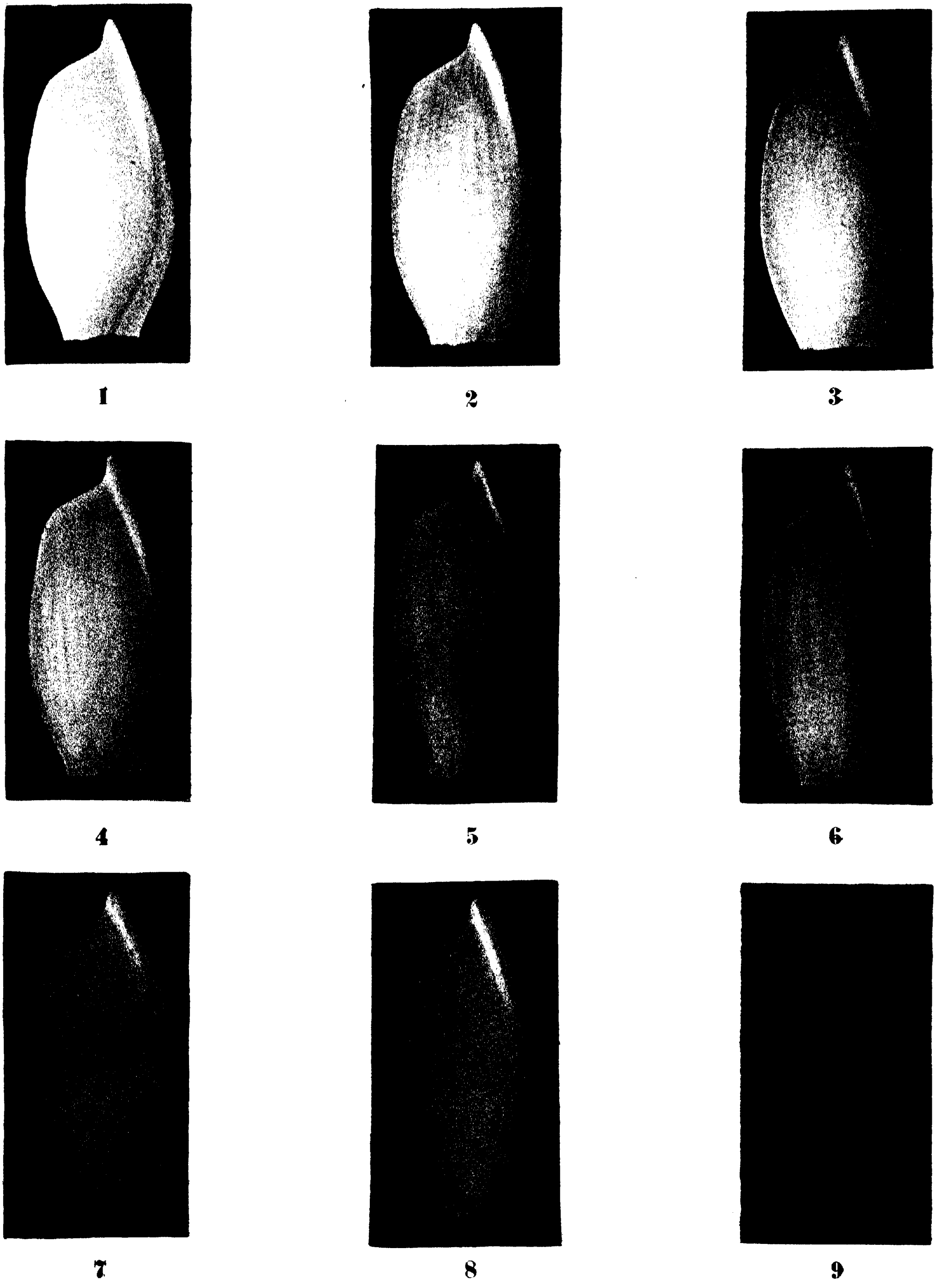


1 2

Awn arrangement : (1) adpressed, (2) spreading



Degree of pubescence : (1) glabrous, (2) sparsely pubescent, (3) densely pubescent



1 2 3

4 5 6

7 8 9

Glume colour : Grades 1 to 9

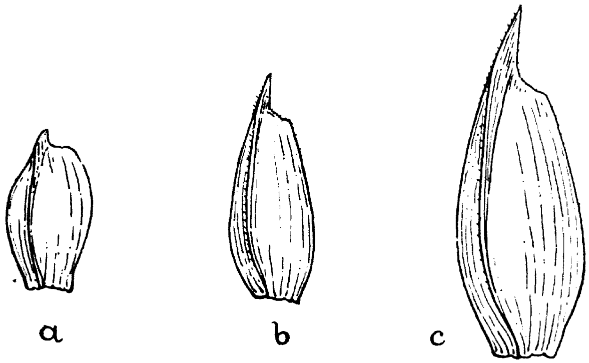


FIG. 1. Glume length: (*a*) short, (*b*) mid-long, (*c*) long

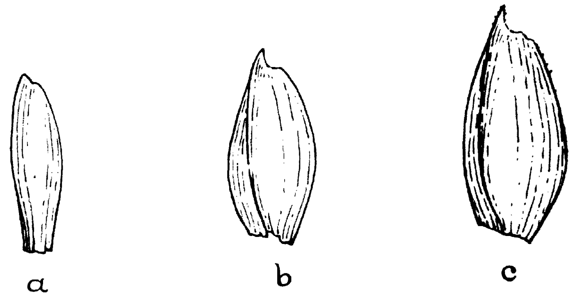


FIG. 2. Glume width: (*a*) narrow, (*b*) mid-wide, (*c*) wide

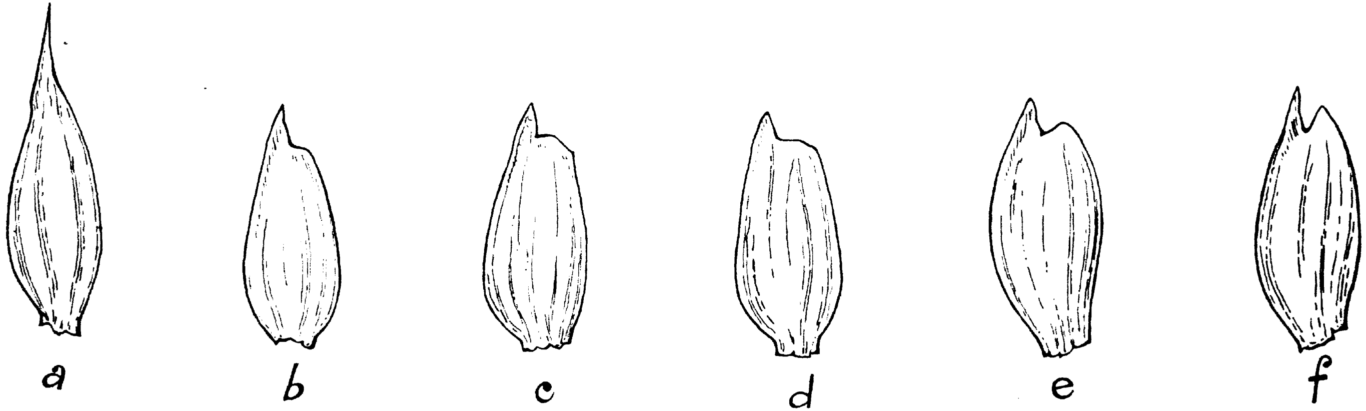


FIG. 3. Glume shoulder shape: (*a*) wanting, (*b*) oblique, (*c*) rounded, (*d*) square, (*e*) elevated, (*f*) apiculate

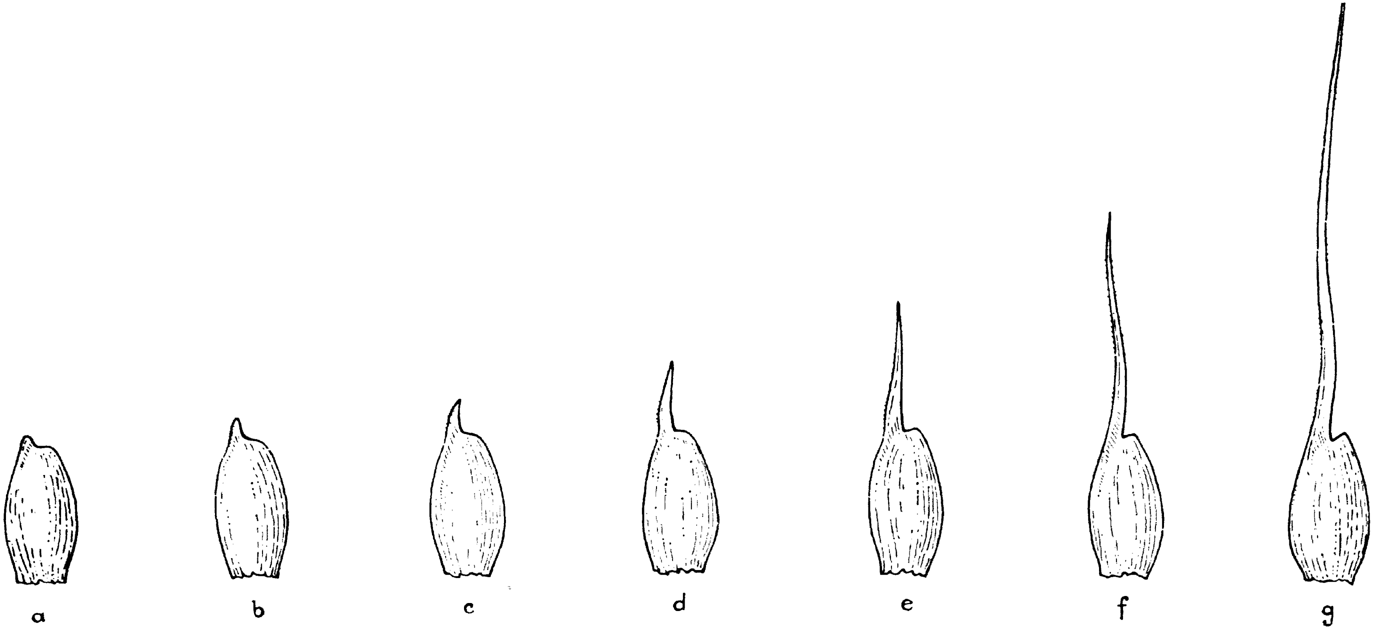


FIG. 1. Beak length : grades *a – g*

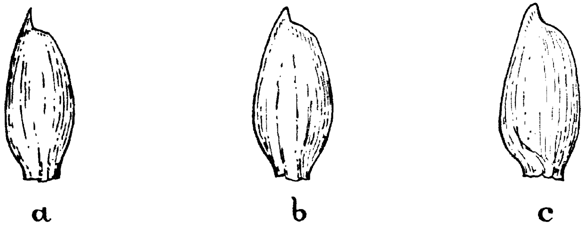


FIG. 2. Beak width: (*a*) narrow. (*b*) mid-wide. (*c*) wide

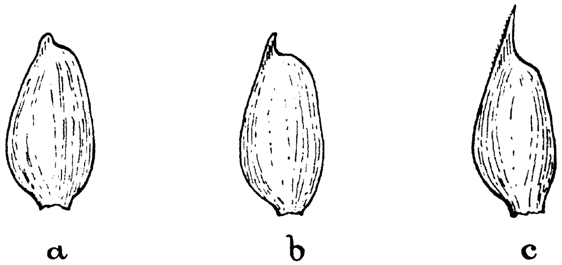
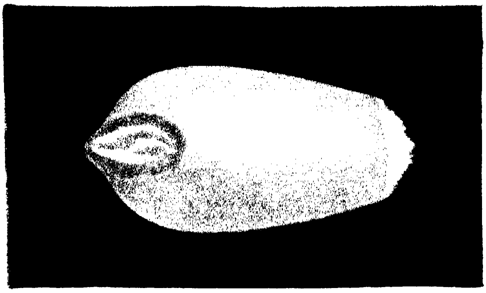


FIG. 3. Beak shape: (*a*) obtuse. (*b*) acute, (*c*) acuminate



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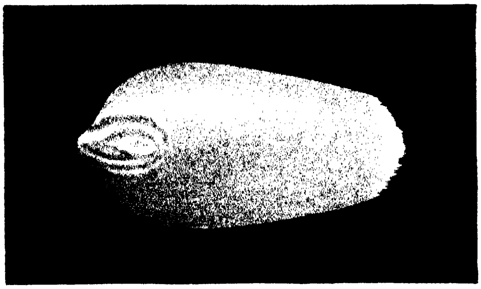

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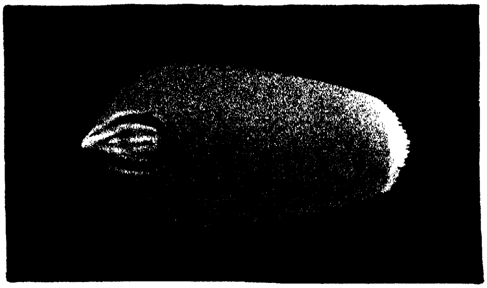

3

Grain colour : (1) white, (2) amber, (3) red

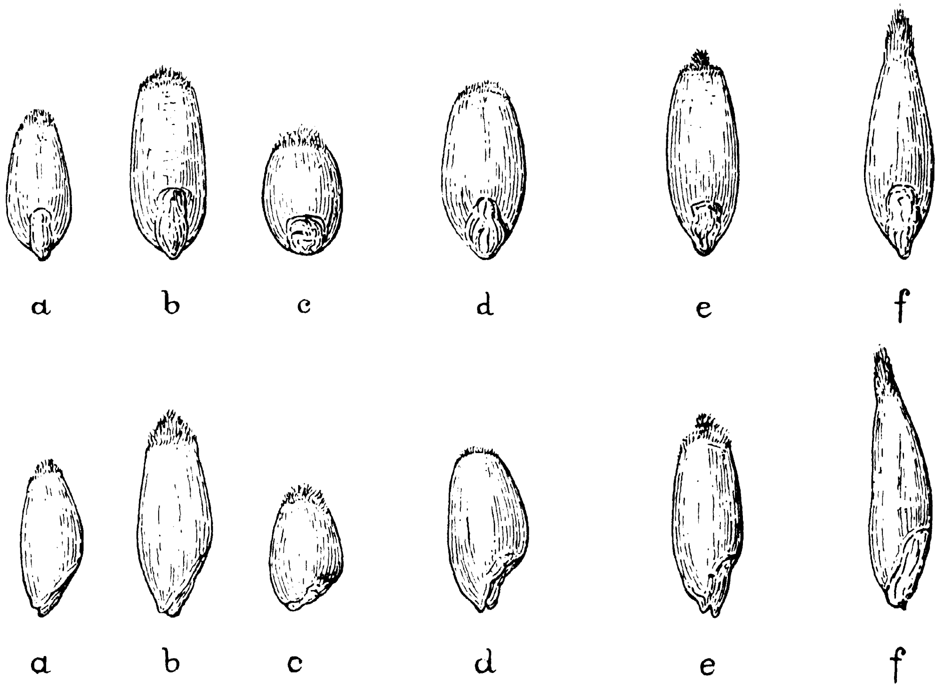

FIG. 1. Grain shape (1st row) : *a,b,c*—*T. vulgare* : ovate, elliptical and oval ; *d*—*T. turgidum* ; *e*—*T. durum* ; *f*—*T. dicoccum*
(2nd row) : side view of the above

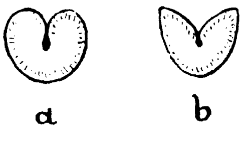

FIG. 2. Cheek shape : rounded and angular

SURFACE RUN-OFF AND SOIL EROSION FROM ARABLE LANDS IN THE BOMBAY-DECCAN

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(With Plates XXXI and XXXII and eight text-figures)

INTRODUCTION

IT is universally recognized that, in the famine areas of the Bombay-Deccan, the most important single factor contributing to crop failures is the inadequacy of soil-moisture which is entirely dependent upon the monsoon rains, often precarious and uncertain in this tract. In an examination of the problem of these crop failures under the Bombay Dry Farming Research Scheme, investigation into the ultimate disposal of rain water naturally forms an important plank in the research programme of the Scheme. It is obvious that a considerable part of the rain water is lost by surface run-off but no definite information regarding the actual quantity of rain water lost in this manner, nor the circumstances under which such losses occur, is available. Rain water, while running over cultivated, fallow or grazing lands, removes part of the surface soil, causing what is known as sheet erosion which is sometimes difficult to recognize. Where such water gains bulk and momentum, e.g. at lower levels, it causes gully erosion which can generally be easily recognized on account of its conspicuous eroding effect. Investigations into the run-off of rain water thus necessarily include the determination of the extent of soil erosion of both the types mentioned above.

Evidence placed before the Royal Commission on Agriculture in India [1926] showed that the action of monsoon rains on the sloping hillsides of upland tracts in peninsular India, more especially in the southern districts of the Bombay province, produces soil erosion similar to that produced by fluvial action of rivers in Northern India. The Royal Commission, therefore, recommended that ' the exact extent of soil erosion in the Bombay Presidency should be investigated.'

In the programme of work under the Bombay Dry Farming Research Scheme at Sholapur, elaborate experiments have been included to determine the loss of rain water by run-off and also the extent of erosion by rainfall on arable lands. Prior to these experiments at Sholapur, experiments of a preliminary nature were carried out under the Soil Physicist to the Government of Bombay at a small Dry Farming Station at Manjri near Poona from 1929 to 1933. The plot, however, on which these early experiments were carried out, had a slope that was much greater than the average slope of the majority of agricultural lands in the Bombay-Deccan. The experiments which are herein described were laid down on a piece of land with a natural slope which could be considered to be typical of the majority of agricultural lands in the Bombay-Deccan. No similar experiments to determine the extent of soil erosion from arable lands have been done before in India and the results presented here are the first of their kind, not only in the Bombay-Deccan, but also in the whole of India.

Sir Archibald Geikie has mentioned in his *Text-book of geology* the huge figure of 356·3 million tons of solid matter as being carried off the land by the Ganges during a single year. Sahasrabuddhe [1929] has given a figure of little less than 100 tons of solid matter estimated to be carried away by the Mula river near Poona on a day during the monsoon. With the exception of such limited references of a general nature, no data of any precise character are available with regard to the quantitative aspect of erosion of arable lands in India.

Some experiments on this subject have been reported by Gorrie [1938] from the Punjab, but these were carried out on forest soils and the plots chosen for experimental work were very small.

A very large number of experiments on rainfall run-off and soil erosion have been carried out at a large number of experimental stations in the U. S. A. and, of late, the subject of soil erosion has received considerable attention all over the world.

II. REVIEW OF PREVIOUS LITERATURE

As an outcome of this work, a mass of data has now been collected and published. In this section, however, only such literature which bears directly on the experiments described in this paper is briefly reviewed. Two comprehensive publications on soil erosion and its control in different countries have been published by Eden [1933] and Jacks and Whyte [1938]. Recently, Gorrie [1939] has compiled a bibliography of Indian work dealing with the subject of soil erosion.

There is a consensus of opinion that all rainfalls do not produce run-off and erosion. Dickson [1929] noticed very heavy erosions with an average annual rainfall of only 21·68 inches. Lowdermilk [1931] found a correlation between run-off and intensity of rainfall. On the other hand, Conner, Dickson and Scoates [1930] failed to establish any direct relation between erosion and intensity of rainfall. They found, however, that run-off was influenced by the moisture content of the soil at the time of rainfall. Christiansen-Weniger [1934] is of the opinion that ' average precipitation is of little importance, the chief factors being maximal precipitation and the distribution of rainfall in the different seasons.' It seems, therefore, that the total rainfall of a tract is no criterion for judging the possibility of the occurrence and extent of erosion. It is the intensity of rainfall that is most responsible for causing run-off and erosion.

The amount of rainfall lost as run-off has been measured by a few workers. Mosier and Gustafson [1918] noticed a marked seasonal variation in percentage run-off. Over a period of three years, the run-off varied from 31 to 50 per cent of the annual rainfall. Gorrie [1938] recorded a run-off varying from 5 per cent, in the case of plots covered with grass and shrub, to 25 per cent from a bare soil. As regards the amount of silt lost per acre as a result of rainfall run-off, the results vary considerably. In Russia [Jacks and Whyte, 1938], the average soil losses varied from 20 tons per hectare per annum on gentle and moderate slopes to 50 tons on steep slopes. In Ceylon, Holland and Joachim [1933] found that, under current estate practices, the loss by erosion varied from 56 to 101 tons per acre during a period of six years. Gorrie [1938], in India, records nearly 8 tons per acre as the amount of soil lost from a bare plot during a single monsoon.

The effect of some sort of cover on soil has been recorded by several workers. Duley and Miller [1923] found that plots under annual crops suffered more than plots under sod. They also noticed that a wide-sown crop, like maize, allowed more run-off and erosion than a close-spaced one. Holland and Joachim [1923] found that soil erosion was greater in control plots than in plots having vegetation. In Africa very similar results were obtained by Thompson [1935] and Staples [1936]. Thompson found that 'annual hay crops were less detrimental. Among perennial planted grasses, Rhodes grass was not effective in preventing erosion and run-off.' Staples obtained the least percentage run-off with perennial grass and deciduous thickets, followed by Bulrush millet. Russian investigators, as quoted by Jacks and Whyte [1938], have come to a similar conclusion as regards the importance of grass in preventing run-off and erosion.

As regards the effect of cultivation, the data of Lowdermilk [1931], Holland [1930] and Duley and Miller [1923] show that cultivation increases the rate of erosion. Duley and Miller's results show that, while cultivation increased erosion, it reduced run-off. Deeper cultivation, however, was found to cause less erosion than shallow cultivation. The results obtained by Miller and Krusekopf [1932] fail to substantiate the common belief that deep ploughing is markedly better than shallow ploughing in reducing erosion losses. The results of Staples [1936], however, show that flat cultivation on a bare plot caused less run-off and erosion as compared with a bare uncultivated plot. Eden [1933] cites other workers who consider deep tillage to be effective in checking erosion, though, in conclusion, he observes that the effect of cultivation must be regarded as an open question.

Duley and Ackerman [1934] recorded a larger percentage run-off from short plots than from long ones. Their results on soil erosion were less consistent but they appear to indicate that, when the rainfall is light, short plots may undergo greater erosion, but that the reverse is true when the rainfall is heavy.

As regards the amount of nutrients removed in the process of soil erosion, Duley and Miller [1923] observe that the losses are in some cases greater than the annual crop requirements. The losses in general follow the trend of the actual losses of soil. Most of the nitrogen is removed from the soil as organic nitrogen, the loss of nitrates being very low. This view was later confirmed by Duley [1926] who found very little nitrates in run-off water. He found that calcium formed the largest proportion of the total nutrients removed in the run-off water.

Miller and Krusekopf [1932] support the findings of Duley and Miller. Their mechanical analysis of the eroded material showed that the uncropped plots lost more sandy material than the others.

Just as soil type influences erosion, erosion changes the soil type. Bennett [1931] gives examples of new soil types having been formed by erosion. In many cases the present surface soil is the original 'B' horizon. This leads to the formation of what are known as truncated profiles. Elsewhere, e.g. in Russia and Africa [Jacks and Whyte, 1938] and in England [Robinson, 1936], similar cases have been recorded.

III. Factors affecting run-off of rain water and soil erosion

The environmental factors that influence the extent of run-off of rain water and of consequent soil erosion are :—

(1) Topography, (2) soil types and their geological origin, (3) vegetation cover and (4) the climatic factors, of which the temperature and the extent and distribution of rainfall are the most important.

The area under the Dry Farming Research Station, Sholapur, is very representative of an extensive tract of the Bombay-Deccan, which is liable to periodic famines and scarcity. This tract includes the three entire districts of Ahmednagar, Sholapur and Bijapur, and also the eastern portions of Nasik, Poona, Satara, Belgaum and Dharwar districts. It forms the area lying between E. longitude 74° and 76° and the parallels of latitude 16° and 21° N. L. and is about 26,000 square miles in extent. The Western Ghats or the Sahyadri range of mountains forms the western boundary of this tract. In fact, the Sahyadri range itself is a comparatively less eroded ridge of hard Deccan trap of volcanic origin. Numerous spurs from the Sahyadri range extend to the east and protrude at right angles to the main range into the tract forming the Bombay-Deccan. The general slope of this region is towards the east. The whole tract, therefore, consists of a plateau or a tableland with gentle undulations intersected by spurs from the Sahyadri range at right angles to the main range, thus forming a series of ridges and valleys across the plateau. The elevation of the Deccan Plateau ranges from about 2,000 ft. in the west to about 1,400 ft. at the eastern boundary of the Bombay province. The geological formation of the whole area forming the Bombay-Deccan from the river Godavari in the north to the river Krishna in the south is the well-known Deccan trap or basalt. To the south of the Krishna river in the Bijapur district, other formations of the transition series and of still older periods are met with. The whole tract which is gently undulating with alternate ridges and narrow valleys, consists of agricultural lands which have undergone varying degrees of erosion, leaving only a thin cover of soil in many places. Along the banks of the rivers, more extensive, level and deep lands are to be found. These topographical features which are the result of geological agencies, influence very greatly the run-off of rain water and the extent of soil erosion in different portions of the tract. A detailed contour map of any portion of the tract shows very distinctly the undulating character of the area. The map of Bijapur taluka (Fig. 1), which is given as an illustration, shows that the area is traversed by a large number of *nallas* and their tributaries. All these *nallas* finally coalesce into larger streams such as the Don or the Krishna rivers and serve as surface drains for the storm-water received during heavy and intensive showers in the monsoon months. Accordingly, every year these rivers and streams carry away millions of tons of suspended soil or silt from the agricultural lands of the tract which mainly consists of the finer and more fertile fractions of soil. The area is characterized by the absence of any large tree growth except in the region of heavy rains just adjacent to the Western Ghats. Even annual vegetation is generally stunted and of very poor growth. The open, bare and uncovered nature of the tract facilitates losses of rain water and contributes to soil erosion on an extensive and widespread scale.

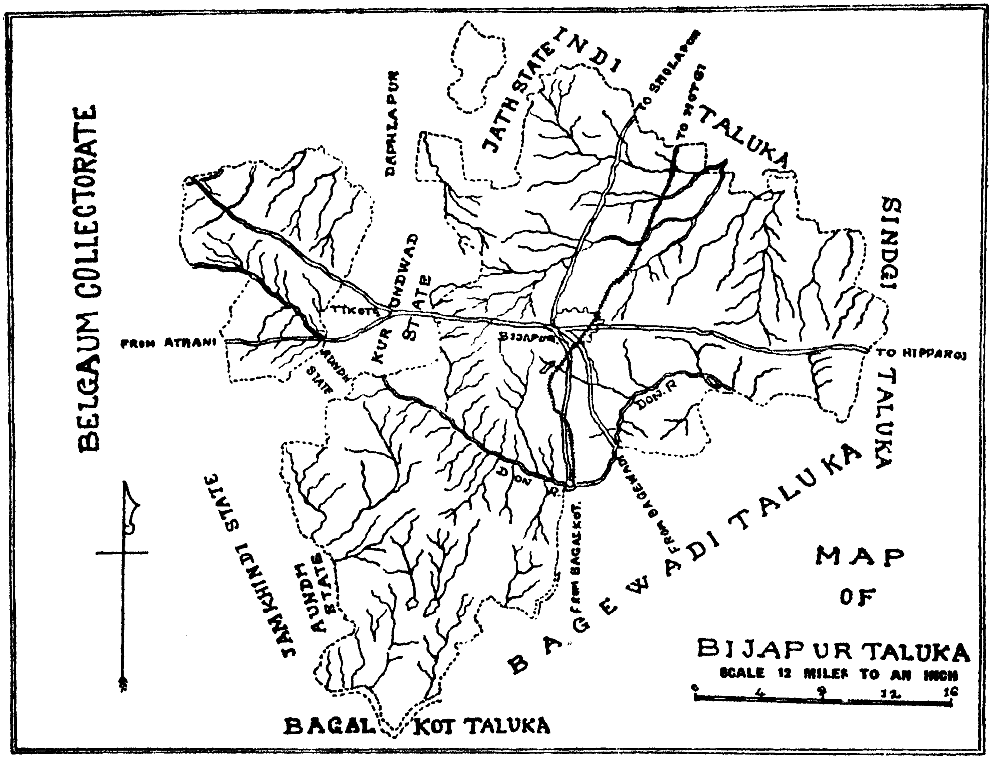

FIG. 1. Map of Bijapur taluka showing natural surface drains

IV. CLIMATIC FACTORS INFLUENCING RUN-OFF AND SOIL EROSION IN THE BOMBAY-DECCAN

(*A*) *Temperatures*

As the atmospheric temperatures of the tract at different periods of the year have an indirect influence on the extent of run-off and erosion, they are discussed here very briefly. In this extensive tract, the prevalent temperatures throughout the year show considerable variance from north to south as well as from west to east. The extent of elevation above sea-level also has considerable influence on prevailing temperatures. If the records of temperatures at the four important district towns are examined (Table I), they clearly indicate the great range through which the seasonal temperatures of the tract fluctuate.

TABLE I*

Record of temperatures at important towns

	Nasik north-western area	Ahmednagar north-eastern area	Sholapur south-eastern area	Bijapur south eastern area
Highest monthly mean maximum (°F.)	100	103	106	104
Lowest monthly mean minimum (°F.)	48	51	56	55
Absolute maximum (°F.) .	107	110	110	108
Absolute minimum (°F.) .	42	44	48	46

* Figures given in Tables I and II are from the Statistical Atlas of the Bombay Presidency [1925].

The highest monthly mean maximum and the lowest monthly mean minimum temperatures show a difference of nearly 50°F. at all stations, while the absolute maximum and minimum show a difference of more than 60°F. during the year. The maximum temperature is reached either in April or May, while the minimum is experienced either in December or January. The air is very dry for six months of the year from November to April. During this period, the soils become extremely dry and loose and are easily blown away by the wind and carried off in suspension by water if a heavy shower of rain is received. More detailed data regarding temperatures and humidity from month to month at Sholapur are given later while discussing experimental work at this centre. The figures given above for the four recording centres illustrate how the maximum temperatures increase from north to south and also from west to east. The minimum temperature is lowest in the northern tract, as represented by Nasik, and gradually rises towards the south, i.e. Sholapur and Bijapur.

(*B*) *Rainfall*

The average monthly rainfall statistics for the same four centres show how the total rainfall, and more particularly its distribution from month to month, vary from west to east.

TABLE II

Average monthly rainfall in inches

Month	Nasik north-western area	Ahmednagar north-eastern area	Sholapur south eastern area	Bijapur south eastern area
January	0·10	0·17	0·15	0·09
February	0·04	0·13	0·07	0·06
March	0·03	0·10	0·20	0·22
April	0·18	0·23	0·46	0·80
May	0·92	0·92	1·05	0·31
June	5·57	4·57	4·67	3·37
July	8·67	3·61	4·20	2·51
August	5·09	2·77	4·54	2·88
September	5·93	6·84	7·71	6·33
October	2·81	2·78	3·02	3·88
November	0·46	0·83	1·05	1·52
December	0·18	0·55	0·46	0·31
Annual total	29·98	23·50	27·55	23·28
Average number of rainy days*	48·6	36·1	41·3	36·1

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* According to the practice adopted by the Meteorological Department, only such days as receive 10 cents or more of rainfall during the 24 hours are counted as 'rainy days'. The same procedure is followed in calculating the data dealt with throughout in this article.

The rainfall at Nasik is typical of the south-west monsoon, which is restricted to a period of five months from June to October. This rainfall is generally evenly distributed during the four months of June to September and is usually received spread over a large number of rainy days. The maximum rainfall is received in July. Under such conditions, the effects of surface run-off and soil erosion are limited. The rainfall at each of the other three stations is similar in character and represents the type of monsoon generally experienced in the eastern parts of the Bombay-Deccan. The rainfall received during the first three months (i.e. June-August) amounts to about 50–55 per cent of the total precipitation, while the remaining rainfall occurs from September onwards. The number of rainy days is limited, especially during the latter part of the season. The rainfall in this tract largely consists of intermittent heavy showers of great intensity. It should be remembered that the figures given in Table II are averages. The actual figures obtained in any one year may deviate very considerably from them. Such variation can be seen from the rainfall figures for five years at Sholapur which are given later.

Two other important factors which influence the climate of the tract are the average wind velocity and the atmospheric humidity. The nature of both these factors in the eastern tract differs considerably from their nature in the western tract of the Bombay-Deccan. These factors tend to make the climate in the eastern tract dry and desiccating even during the monsoon months, and, in this area, facilitate the quick drying of the surface soil after it has become loose and pulverized by such agricultural operations as harrowing and weeding. Therefore, the heavy downpours of rain, common in September and October, cause serious losses of such dry, loose and pulverized soil by erosion.

V. EXPERIMENTS ON RAINFALL RUN-OFF AND SOIL EROSION AT THE SHOLAPUR DRY FARMING RESEARCH STATION

To begin with, experiments were laid down with a view to finding out as accurately as possible the amount of rain water lost by surface run-off and to enable an approximate estimate to be made of the total amount of soil carried off annually by erosion on a representative soil of the tract under the different methods of cultivation and cropping common in the south-eastern part of the Bombay province. The slope of the land chosen for this experimental work was as far as possible selected so as to be representative of the average slope to be found on the majority of the cultivated fields in the tract. The experiments were laid out on the same plan as was followed by Duley and Miller [1923] in their classical experiments at Missouri in the U. S. A., but due to differences in local environment, the plot dimensions chosen and the slope used were somewhat different from those adopted by these workers.

VI. SOIL TYPE AND ITS PHYSICAL AND CHEMICAL CHARACTERS

The soil of the experimental plots can be described as medium deep soil the depth varying from 9 in. to 18 in. This soil is derived from decomposition of the Deccan trap and is of a residual type, a portion of the 'A' horizon having been lost by previous erosion. Such decomposed trap is found immediately below the comparatively thin layer of surface soil. The colour of the soil is dark brown and it shows a compact constitution with the texture of heavy clay. The mechanical composition of the soil as determined by the International Soda Method is given below.

These data indicate that the soil contains a very high percentage of clay and can therefore be classified as belonging to the heavy clay type. Study of some of the physico-chemical constants indicates that this soil has a high moisture equivalent of 43·6, a high wilting coefficient of 20·10, sticky point of 57·7, with a shrinkage value of 62·7. The total exchangeable bases have been found to be 38·4 m.e. of which exchangeable lime is 30·0 m.e. It has a wide C : N ratio of 17 : 1 and the *p*H value of 8·14. The chemical composition of the soil, determined from the results of analysis by digestion with hydrochloric acid, is given in Table IV.

TABLE III

Mechanical analysis of soil of experimental plots

Expressed on per cent dry matter

	Surface layer 0—9 in.	Sub-surface layer 9—18 in.
Stones per cent on original soil	5·28	6·87
Loss by solution	1·64	2·67
Coarse sand	0·71	2·34
Fine sand	11·67	9·18
Silt	26·86	26·33
Clay	58·49	58·60
Difference	0·63	0·98

TABLE IV

Chemical analysis of soil of experimental plots

Expressed on per cent dry matter

	Surface layer 0—9 in.	Sub-surface layer 9—18 in.
Loss on ignition	7·73	8·58
Sand and silica	65·65	64·42
Iron oxide (Fe_2O_3)	10·99	10·48
Aluminium and titanium oxides (Al_2O_3 + Ti_2O_3)	11·48	11·29
Lime (CaO)	1·48	2·32
Magnesia (MgO)	0·35	0·79
Potash (K_2O)	0·44	0·48
Phosphoric acid (P_2O_5)	0·06	0·05
Nitrogen (N)	0·039	0·040

These figures show that the loss on ignition is high and is largely due to the combined moisture held by the colloids resulting from the high percentage of clay. The amount of sand and silica is comparatively high. The proportions of iron oxide and aluminium oxide are nearly equal. Phosphoric acid and nitrogen are both low, but other important plant-food ingredients, such as lime and potash, are adequate from the point of view of dry crop cultivation. The experiments described hereafter were conducted on this type of soil which can be taken as a typical representative soil to be found throughout the tract.

VII. Plan and equipment of the experimental plots

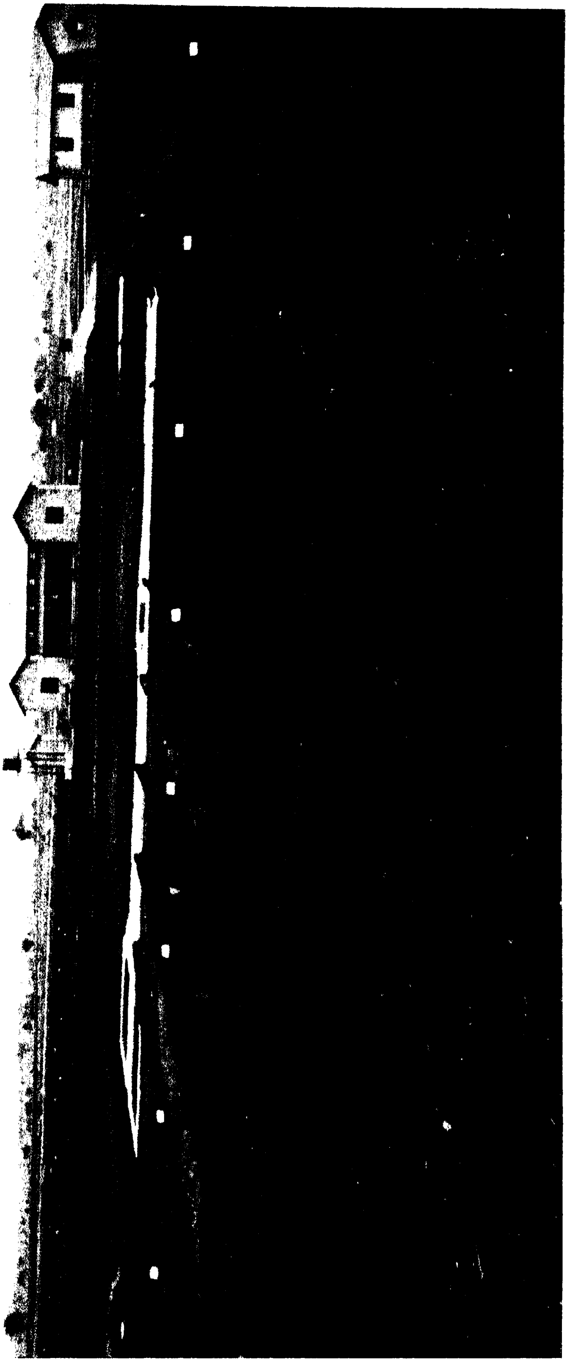
The area of the experimental plots was surveyed and the levels were determined at a distance of every 5 ft. The major slope was found to be in the north-westerly direction and the lay-out of the experimental plots therefore was fixed in the same direction. Eight unit plots were laid out. The size of each unit plot was fixed at ½ *guntha* or 1/80th of an acre for seven plots, the shape being a long narrow rectangle having its breadth and length in the proportion of 1 : 8. In the case of the eighth plot, the length was 16 times the breadth and the size of this plot was one *guntha* or double that the others. The average slope of all plots was 1·18 per cent (fall of 1 in 84). As the length of each of the seven plots was 66 ft., the total vertical fall in each plot was 0·78 ft. In the eighth plot, the length was 132 ft. and the total vertical fall from top to bottom was 1·56 ft. Each plot was surrounded on three sides by galvanized iron sheets 18 in. wide, half of which were buried in the ground and fixed by means of stout iron stakes at a distance of 4 ft. apart. The fourth and lower side of each plot was open and was level with the top of the side wall of a series of masonry tanks constructed at the lower end of each plot to catch the run-off of rain water and silt. Each tank had a flat bottom. Seven of these masonry tanks had dimensions of 8 ft. × 3·3 ft. × 3 ft., while the eighth one was 8 ft. × 5 ft. × 4 ft. An outlet pipe was provided in each tank which could be opened or closed as required. The ground-plan of the eight experimental plots and the tanks is shown in Fig. 2. All the outlet pipes opened into a drain whence the water from the tanks could be allowed to escape through an underlaid china pipe of 4 in. diameter to outside the experimental area. Plates XXXI and XXXII illustrate the general arrangement of the experimental plots and the tanks.

VIII. Treatment of the experimental plots

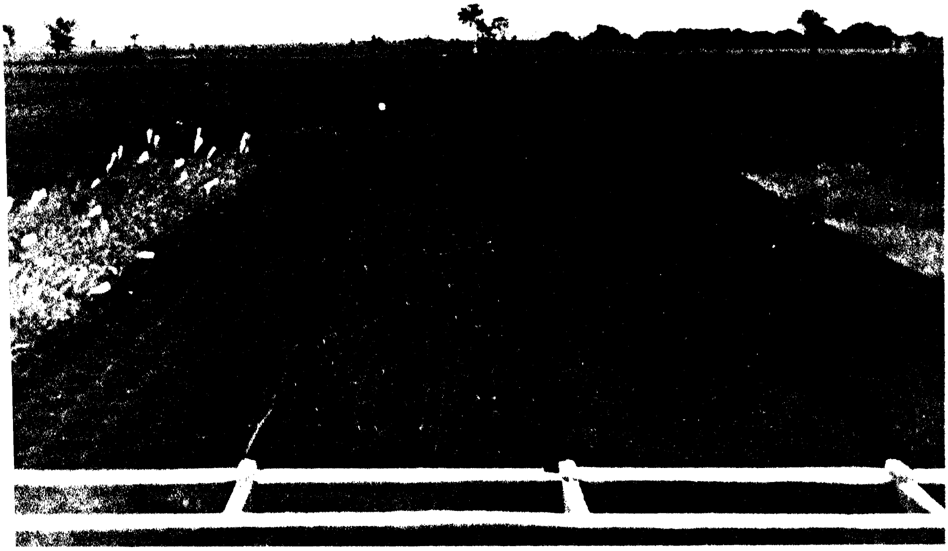
The undernoted eight treatments were given respectively to the eight plots mentioned above.

Plot 1 : Retention of natural vegetation or sod (Treatment 1)

This plot was kept unstirred and in its original condition, i. e. covered with the usual annual flora which was rather sparse at the commencement of the experiment. This vegetation was allowed to grow and develop naturally during the monsoon and to dry up during the hot weather months. During the five years' experimental period, the whole plot became completely covered with vegetation. In the hot weather, much of this vegetation dried up, but generally sprouted again during the monsoon. The most common species of plants present were : *Cynodon dactylon, Ischaemum pilosum, Euphorbia*



A general view of plots for run-off and soil erosion experiments at Sholapur



Some of the run-off plots with tanks

hyperecifolia, *Justicia quinqueangularis*, *Tridax procumbenx*, *Tephrosia purpurea*, *Indigofera linifolia*, *Merremia emarginata*, *Panicum isachne*, *Panicum ramosum*, *Iseilema anthophoriodes*, *Cocculus villosus*, *Euphorbia dracunculoides*, etc.

Plot No.	Treatment	Plot No.	Treatment
1	Weeds preserved	5	'Scooped'
2	Weeds removed	5	*Kharif* crop of *bajri* and *tur*
3	Harrowed only	7	Ploughed and harrowed
4	*Rabi* crop of *jowar*	8	Ploughed and harrowed with double length

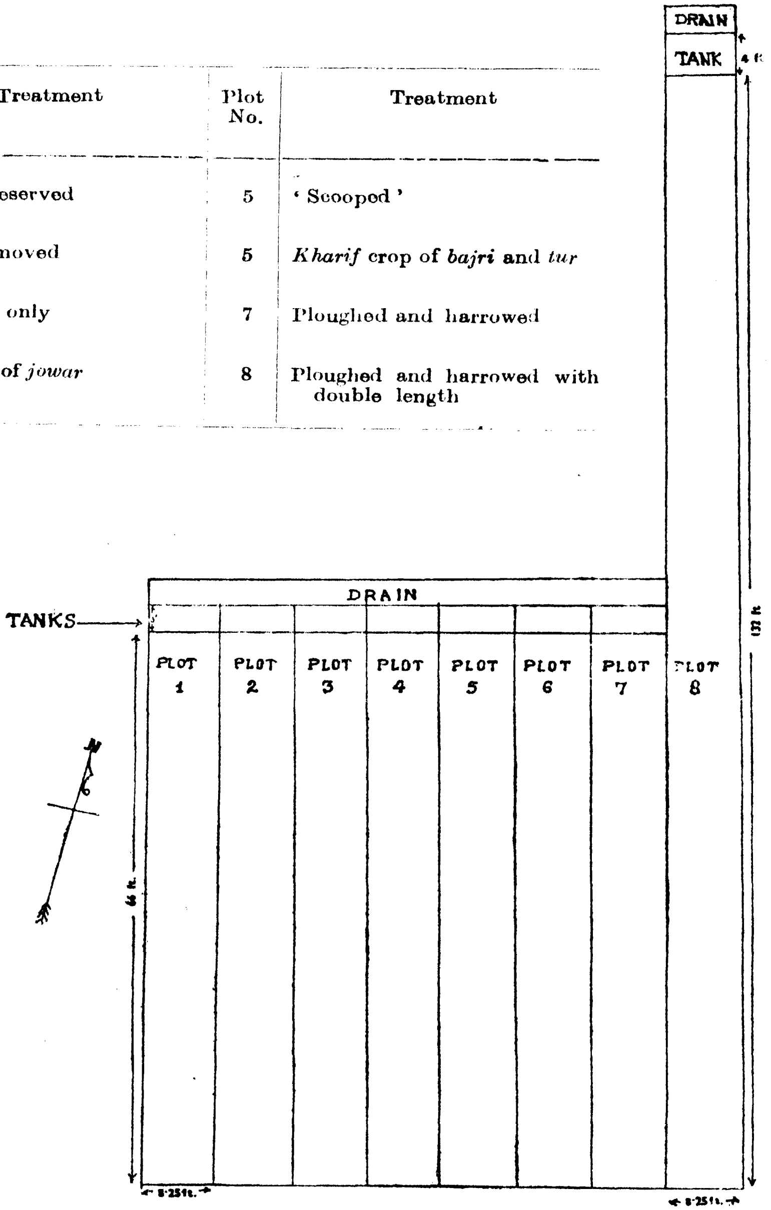


FIG. 2. Plan of the run-off and erosion experiments at Sholapur

Plot 2 : Removal of natural vegetation by cutting (Treatment 2)

The natural vegetation on this plot was superficially removed by cutting close to the ground without disturbing the surface soil. This was done annually, two or three times during the monsoon, whenever the vegetation had grown enough (one to two inches above ground) to interfere with the run-off.

Plot 3 : Shallow cultivation by local harrow (Treatment 3)

This plot received only such cultivation as is usually given by cultivators in the tract. Such cultivation is shallow and, for this purpose, the country blade harrow is the common implement used by the cultivator. The plot was harrowed to a depth of 4 in. two or three times during the season, once in the hot weather before the monsoon (May-June) and twice during the monsoon (July-September) before the sowing season.

Plot 4 : Cultivation of a rabi *crop of* jowar *(Treatment 4)*

In this plot, ploughing was done in the hot weather and subsequent harrowing was done every month from May to September. In the first year, the ploughing was carried out with a CT2 plough but, in the succeeding four years, the plot was hand-dug in order to get the effect of ploughing as actual ploughing was found to be impossible on account of the iron sheets fixed along the borders of the plots. A *rabi* crop of *jowar* (*Andropogon sorghum*) was sown at the beginning of October and received about four interculturings at an interval of about three weeks during November-January.

Plot 5 : Cultural treatment with a 'scooper' (Treatment 5)

The 'scooper' is a specially devised bullock-drawn implement which makes a number of shallow hollows or pockets when worked over a well-prepared soil. By the use of this implement, about 150 'scoops' or hollows were made over the surface of the plot, the intention being that the rain water should be held in these 'scoops' and run-off checked. The size of each hollow or 'scoop' was about 15 in. × 9 in. × 3 in. and the space between two 'scoops' was about 12 in. The scooping was done on two occasions, once early in July and again late in August.

Plot 6 : Cultivation of a kharif *crop of* bajri *and* tur *(Treament 6)*

After a thorough preparatory tillage consisting of one ploughing and two harrowings, this plot was sown with *bajri* (*Pennisetum typhoideum*) and *tur* (*Cajanus indicus*) mixture every year. In sowing this mixture either in June or July, the usual cultivators' practice of sowing three rows of *bajri* and the fourth row of *tur* was followed. The rows ran across the slope so as to obtain the fullest effect of the standing crop in checking rainfall run-off and soil erosion. Four to five interculturings were given to the standing crop at an interval of three or four weeks during July-October.

Plot 7 : Thorough and intensive preparatory tillage (Treatment 7)

In this plot, intensive preparatory tillage was given, which consisted of deep ploughing in the hot season and harrowing four times during the monsoon from June to September. In the first year, the ploughing was done with a CT2 plough, but later on the plot was hand-dug to imitate ploughing. The furrows were made across the slope. No crop was cultivated.

Plot 8 : Treatment 7 on a plot double the length of plot 7 (*Treatment 8*)

This plot received similar treatment as was given to plot 7, i.e. intensive preparatory tillage consisting of ploughing and four harrowings. In this plot the effect of the greater length of the plot on the run-off and erosion was under study as the length of this plot was 132 feet, or double that of plot 7 and other plots.

NOTE.—Treatment 4 was carried out on plot 7 in the first year of the experiment and treatment 7 on plot 4 but, during the remaining four-year period, treatment 4 was continuously on plot 4 and treatment 7 on plot 7. The reason for this change was to avoid the sheltering effect of the standing crop of *bajri* and *tur* of plot 6 on the *jowar* crop of plot 7, as laid out in the first year. As plot 6 was to the west of plot 7, the standing crop on the former plot used to intercept the showers of the south-west monsoon and thus affect the growth of the *jowar* crop on plot 7.

IX. MEASUREMENT OF THE RUN-OFF WATER AND THE RESULTS OBTAINED FROM JUNE 1934 TO MAY 1939

The experimental work started on 1 June 1934, when the construction of the tanks and the lay-out of the eight plots were completed.

Whenever run-off of rain water took place, measurements of the depth of the accumulated water in each plot-tank were taken as accurately as possible, an average of six readings correct to a tenth of an inch being calculated. The volume of water was then calculated on the basis of the known tank dimensions after making correction for the rainfall received directly into the tank. The water in each tank was then thoroughly agitated by stirring, and allowed to escape through the outlet near the bottom of the tank. A sample of this water was taken in a Winchester bottle, care being taken to obtain a fair sample. The quantity of suspended silt was determined in the laboratory by filtering the water through a filter paper and then by drying and weighing the residual material. The actual volume of water was then calculated by deducting the calculated volume of silt from the combined volume of water and silt. The amount of run-off from each plot was calculated both as cubic feet of water collected in each tank and as inches of rainfall lost. The results obtained over five years are given in Table V, which shows the equivalent inches of rain water lost by run-off annually from each of the eight plots receiving the different treatments described above.

On account of the expensive nature of the lay-out required for these experiments, they were conducted on single plots only. It will be shown in Appendix II by the analysis of variance that variation between plots is extremely small when the data of plots similarly treated over some period are worked out statistically.

X. RAINFALL AT SHOLAPUR DURING THE PERIOD OF THE EXPERIMENT

Before discussing the results of the experimental work on run-off, it is necessary to examine how the rainfall varied during the experimental period of five years and how far it represented the average rainfall obtained in this tract over a prolonged period, both with regard to the total annual rainfall and its monthly distribution.

In Table VI, data regarding monthly and annual rainfall at the Research Station along with the number of rainy days are given. In column 2 of this table, the average monthly and annual rainfalls for a period of 25 years from 1908 to 1933, i.e. just prior to the commencement of the experiments, are given. Columns 3-7 give similar data for the five years of the experiments, while in the last column, the average monthly and annual rainfalls and the number of rainy days for the whole period of five years (1934-39) are given along with their deviations from the annual average. It may be seen, by comparison of columns 2 and 8, that the average annual rainfall for the shorter period of five years was practically the same as the annual average over the longer period. The average distribution differed, however, in the two periods. The average rainfall of the three months from June to August was somewhat higher during the shorter period than during the longer period. On the other hand, the rainfall during September and October was somewhat lower during 1934-39 than during the previous 25 years' period, i.e. from 1908 to 1933. The number of rainy days per annum did not differ much. Curves showing the average monthly distribution during the two periods readily illustrate the above points (Fig. 3). If the individual years are considered separately, then it can be seen that the years 1934-35 and 1936-37 were years of drought when only 80 and 60 per cent, respectively, of the annual average rainfall were received. The year 1937-38 received very nearly the annual average rainfall. The remaining two years, viz. 1935-36 and 1938-39, were wet years and received rainfall higher than the annual average. This increase, however, was only 20 per cent in the former year but was nearly 40 per cent in the latter. In the year, 1938-39, the number of rainy days was also much higher, viz. 57 as against the normal average of 41·2. It can be seen therefore that the period of experimentation may be taken as fairly typical in covering possible variations in individual years and, at the same time, giving approximately average rainfall conditions over the total period of five years similar to those experienced over a long period of 25-30 years. Fig. 4 indicates the variation in the monthly distribution of rainfall during the five years of the experimental work. It can be seen from the data in Table VI that no exact relationship appears to exist between the number of rainy days in a year and the total rainfall received during the same period. Although it is true that in general the higher the number of rainy days, the greater the total rainfall and *vice versa*, this is not always the case. Thus, in the year 1937-38, the rainfall was nearly 25 per cent higher than that of 1934-35, but the number of rainy days was smaller, viz. 42 in the former year as against 46 in the latter year. Again the year 1935-36 received nearly 40 per cent more rain than the year 1934-35, but the total number of rainy days in both the years was exactly the same.

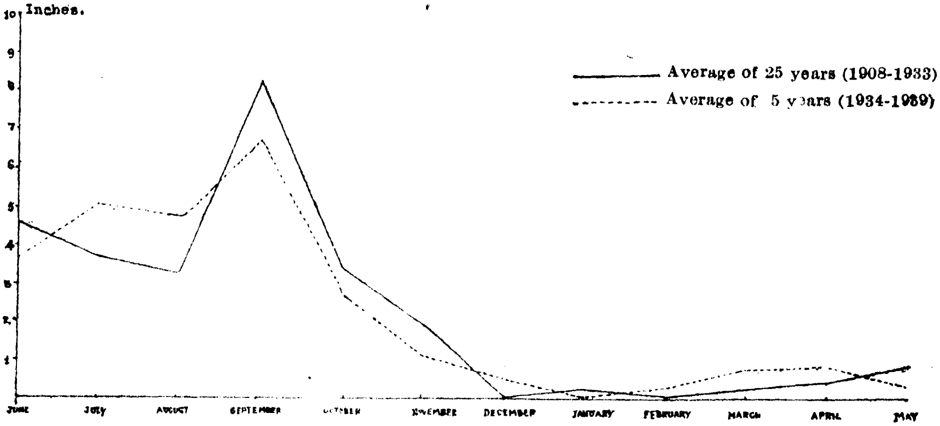


FIG. 3. Average rainfall at Sholapur

TABLE V

Quantities of water lost by rainfall run-off in inches from each plot during the five years of experiment

No. of plot	Treatment	Rainfall lost in inches				
		June 1934—May 1935	June 1935—May 1936	June 1936—May 1937	June 1937—May 1938	June 1938—May 1939
1	Retention of natural vegetation .	0·21	4·02	0·07	0·65	0·64
2	Natural vegetation removed by cutting	1·37	5·80	1·06	6·36	9·48
3	Shallow cultivation by harrowing .	1·24	5·70	2·22	8·36	9·51
4	Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*	1·09	5·55	1·89	7·47	6·92
5	'Scooping' of the surface soil after thorough cultivation	0·02	3·83	0·19	4·32	2·01
6	Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture	0·58	4·62	1·58	6·99	4·41
7	Thorough and intensive cultivation by ploughing and harrowing	1·42	5·02	1·93	7·14	6·41
8	Thorough and intensive cultivation as in plot 7 with double length	1·21	5·31	2·10	7·74	6·30

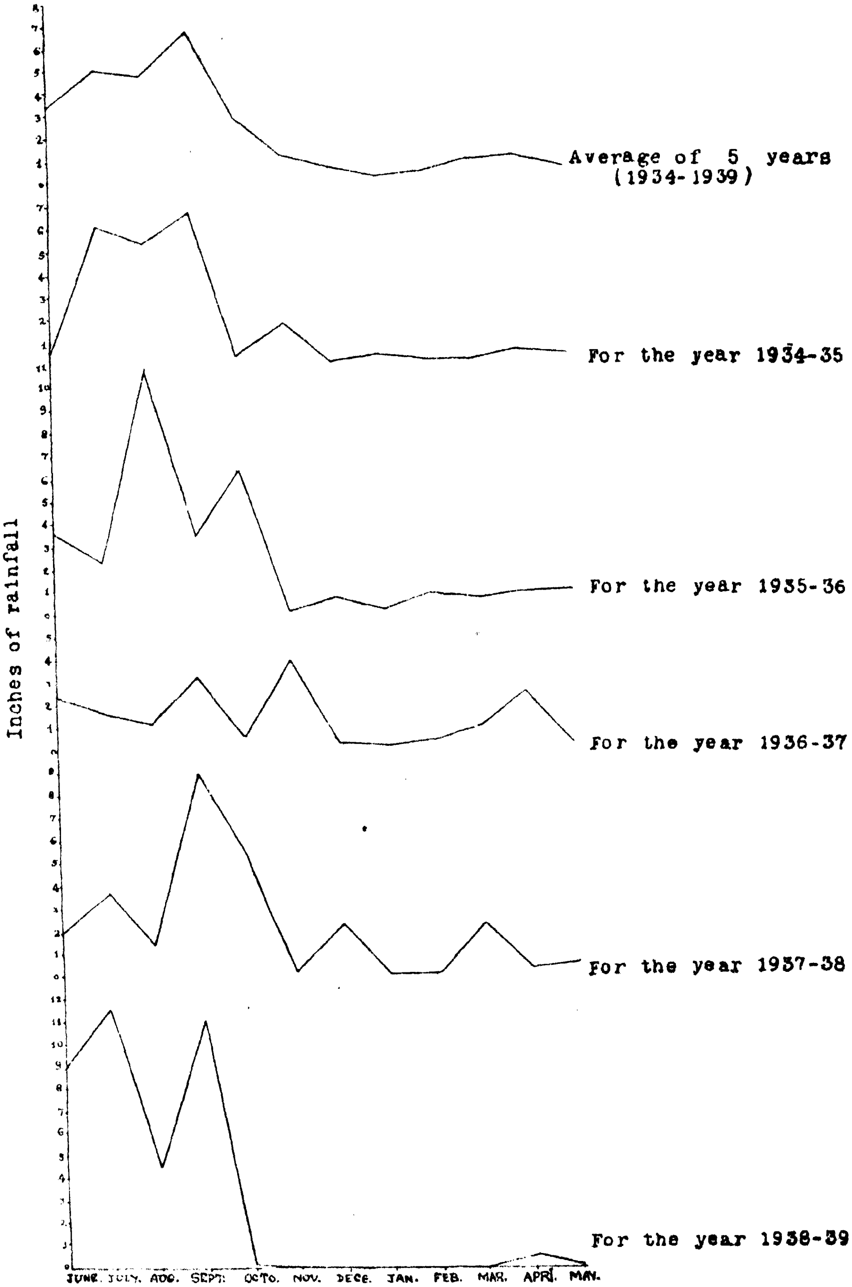


FIG. 4. Average monthly rainfall at Sholapur during the experimental period

TABLE VI

Rainfall and the number of rainy days at Sholapur

Calender months	Average for 25 years		1934-35		1935-36		1936-37		1937-38		1938-39		Average for the years 1934-39	
	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days
June	4·55	6·6	0·59	3	3·54	10	2·43	4	1·92	2	8·45	13	3·39	6·4
July	3·70	7·7	6·06	13	2·26	6	1·62	5	3·65	12	11·59	19	5·04	11·0
August	3·15	7·6	5·33	9	10·84	11	1·10	3	1·53	4	4·53	12	4·67	7·8
September	8·10	9·0	6·56	12	3·44	6	3·12	5	8·96	11	11·02	9	6·62	8·6
October	3·30	4·3	0·28	2	6·39	7	0·47	1	5·12	5	1·06	2	2·66	3·4
November	1·75	1·5	1·62	3	0·01	...	3·75	3	...	...	...	...	1·08	1·2
December	Trace	0·6	...	...	0·56	1	0·05	...	2·08	3	...	...	0·54	0·8
January	0·15	0·3	0·19	1	...	...	...	...	...	...	...	...	0·04	0·2
February	...	...	...	...	0·73	2	0·23	1	...	...	...	...	0·19	0·6
March	0·20	0·4	...	...	0·36	1	0·75	2	2·21	2	...	...	0·66	1·0
April	0·40	1·0	0·41	2	0·65	1	2·40	4	0·23	1	0·49	2	0·84	2·0
May	0·75	2·2	0·11	1	0·74	1	...	...	0·41	2	...	...	0·25	0·8
TOTAL .	26·40 ±1·53	41·2	21·15	46	29·52	46	15·92	28	26·11	42	37·14	57	25·96 ±3·62	43·8 ±0·09

Similarly, monthly rainfall is not always proportional to the number of rainy days in the month. This is due to the fact that the intensity of rainfall is different in different months, as can be seen clearly from the figures given in the last column of Table VI. It can be stated in general that the intensity of rainfall is greater in the latter half of the monsoon, i.e. from September to November, than in the first half, i.e. from June to August. The month of July gave the largest average of rainy days but the intensity of rainfall in this month was the lowest. It should be noted that the rainfall during the period of September to November is generally received in the shape of stormy downpours lasting for only an extremely short period of one to two hours daily. The rainfall during the early period of the monsoon is generally received as small showers of a persistent and soaking nature, lasting over a large number of hours each day. This shows that the early monsoon rains are generally of low intensity while those of the later period are of great intensity. This intensity of rainfall has a very great bearing on the run-off of rain water and on consequent soil erosion.

XI. TEMPERATURES, HUMIDITY AND WIND VELOCITY AT SHOLAPUR

Mention has already been made of the influence of climatic factors, other than rainfall, on the run-off of rain water and on consequent soil erosion. In Table VII monthly average values for some of the more important meteorological observations taken during the experimental period of five years, i.e. 1934-35 to 1938-39 are given.

TABLE VII

Monthly averages of important meteorological observations at Sholapur Dry Farm

(Average of 5 years from 1934-35 to 1938-39)

Month	Maximum temperature (°F.)	Minimum temperature (°F.)	Mean temperature (°F.)	Relative humidity per cent	Wind velocity miles per hour	Evaporation from free water surface in inches
June	94·23	73·35	83·79	73·94	10·78	11·79
July	88·43	70·94	79·65	82·34	10·40	8·61
August	88·15	70·02	79·10	81·03	9·43	8·17
September	86·84	69·53	78·19	82·40	7·31	7·80
October	90·04	66·53	78·30	65·79	5·78	10·77
November	86·17	58·82	72·50	58·94	5·04	8·63
December	84·28	55·93	70·12	58·99	4·44	8·66
January	86·47	56·96	72·62	55·30	4·13	9·94
February	90·78	60·65	75·72	47·57	4·72	10·81
March	97·90	67·33	82·52	34·97	5·12	16·30
April	101·06	72·37	86·73	40·90	6·05	17·22
May	105·41	76·44	90·93	43·57	7·72	20·43

The data of monthly average maximum and minimum temperatures indicate the wide range of temperatures prevailing in this tract. The very high temperatures during April and May result in considerable sun-drying and baking of soils, which causes considerable cracking and fissure formation in the deeper types of soils. These cracks ultimately give rise to gully formation as a result of the run-off of heavy rains at the outbreak of the south-west monsoon. The higher temperature of the atmosphere, combined with the high wind velocity during the monsoon months, produces a highly desiccating effect on the soils. Slight showers are, at that time, ineffective as the soil moisture is largely lost by evaporation during the following 24 hours. The high rate of evaporation of water noted from free water surface indicates a similar trend of rapid evaporation of soil-moisture. These factors result in the surface soil remaining dry and pulverized, thus facilitating its removal by the run-off water resulting from the heavy showers commonly received in September and October in this tract. The knowledge of the influence of such climatic factors facilitates a clearer understanding of the experimental results on run-off and soil erosion which are discussed hereafter.

XII. Results of rainfall run-off experiments at Sholapur

(*A*) *Effect of experimental treatments*

The eight different treatments given to the eight plots in the experimental area have already been mentioned in detail. The main object of these different treatments was to ascertain whether any particular method of tillage or cultivation or the growing of any particular crop would have a controlling effect on the quantity of water lost by run-off. The results of the experiments given in Table V were obtained from the estimate of the actual volume of water lost from the area of 1/80th or 1/40th of an acre in cubic feet from year to year and are expressed in inches of rainfall thus lost. Table VIII shows the number of occasions upon which run-off of rain water took place in each year and also the total number of such run-offs during the five years under each plot treatment. The quantities of water lost from each plot in inches are also shown. Careful scrutiny of these results shows that the treatment on plot 1, viz. the plot with natural vegetation preserved *in situ* gave the lowest number of run-offs and lost the smallest quantity of rain water by run-off during the experimental period of five years. In this plot, there were, in all, 23 run-offs during the five years and the total quantity of rain water lost in this way amounted to 5·59 in. during the same period. This treatment was, therefore, the most effective in checking the loss of rain water by surface run-off. The treatment given on plot 5, which consisted of 'scooping', ranked second in effectiveness in controlling run-off. The number of run-offs on plot 5 during five years was 31 or nearly 25 per cent more than on plot 1, but the total quantity of rain water lost amounted to 10·37 in., which is nearly 85 per cent more than the loss on plot 1. Only one more treatment, viz. the cultivation of *bajri* and *tur* crops on plot 6 showed some appreciable effect in controlling rain water run-off. The number of run-offs in this plot was 43 and the water lost amounted to 18·28 inches. If, however, the results from plot 6 are compared with the results obtained on plot 1, i.e. vegetation cover, the number of run-offs on the former plot was nearly double

TABLE VIII

Number of run-offs from each plot and inches of rainfall lost from each plot in different years

Year of observation	Plot 1 Retention of vegetation		Plot 2 Removal of vegetation		Plot 3 Shallow cultivation		Plot 4 Cultivation of *rabi jowar*		Plot 5 'Scooping'		Plot 6 Cultivation of *kharif bajri* and *tur*		Plot 7 Thorough cultivation		Plot 8 Thorough cultivation and double-length	
	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)
1934-35 .	5	0·21	5	1·37	5	1·24	5	1·09	4	0·02	6	0·68	6	1·42	5	1·21
1935-36 .	6	4·02	9	5·80	9	5·70	8	5·55	6	3·83	6	4·62	7	5·02	6	5·31
1936-37 .	3	0·07	5	1·06	5	2·22	4	1·89	3	0·19	3	1·58	4	1·93	4	2·19
1937-38 .	7	0·65	16	6·36	20	8·36	16	7·47	11	4·32	15	6·99	16	7·14	15	7·74
1938-39 .	2	0·64	15	9·84	15	9·51	13	6·92	7	2·01	13	4·41	13	6·41	13	6·30
Total in 5 years	23	5·59	50	24·43	54	27·03	46	22·92	31	10·37	43	18·28	46	21·92	43	22·75
Average per annum	4·6	1·12	10	4·88	10·8	5·40	9·2	4·58	6·2	2·07	8·6	3·65	9·2	4·38	8·6	4·55

that on the latter and the quantity of water lost more than three times. The *bajri* crop stands for 3-3½ months during the south-west monsoon period and the *tur* crop remains much longer. The combined effect of these standing crops in checking run-off can be seen in the results obtained on plot 6 if compared with those of plot 7.

The treatment given in plot 2, where the natural vegetation was removed by cutting close to the soil surface without disturbing the soil itself, showed by contrast the great preserving effect on soil erosion of the plant cover on plot 1. The soil in both cases was undisturbed, but there was a vegetation cover in plot 1 and no such cover in plot 2. Treatment on plot 2 gave in all 50 run-offs and lost a total of 24·43 inches of water during the five years. The number of run-offs was more than double that on plot 1 during that period and the rain water lost by run-off on plot 2 was more than four times that lost on plot 1 which had plant cover. It was observed that this plot used to get dry and crack extensively during the hot weather. This cracking facilitated the vertical percolation of rain water and thus reduced the loss of rain water by surface run-off.

The treatment on plot 3 consisted of shallow cultivation, viz. two or three harrowings during the monsoon months done with a blade harrow. This plot gave the largest number of run-offs, viz. 54 and also lost the largest total quantity of rain water, viz. 27·03 in., during the complete period of five years. The difference of 2·6 inches in the total water lost by run-off between plots 2 and 3 was mainly due to higher loss from plot 3 in one year. During the year 1937-38 which gave a greater number of intensive showers, there were four additional run-offs and 2 in. excess loss of rain water from plot 3 as compared to plot 2. That the difference between the treatments on plots 2 and 3 is not statistically significant, is shown later on in another statement.

The treatment on plots 7 and 8 consisted of thorough and intensive cultivation of the land by one deep ploughing in the hot season, followed by four or five harrowings during the monsoon months. The length of plot 8 was double that of plot 7. The total number of run-offs during five years was 46 from treatment on plot 7 and 43 from treatment on plot 8. The total quantity of water lost was 21·92 in. and 22·75 in. from plot 7 and plot 8 respectively. As compared to no cultivation on plot 2, or shallow cultivation on plot 3, the run-off was somewhat lower in the case of the deeper cultivation on plots 7 and 8. There was no noticeable difference due to the different lengths of the two plots. This is contrary to the result obtained by Duley and Ackerman [1934] in the U. S. A. They found that the shorter plots gave a larger percentage of surface run-off than longer plots. Thus, although the thorough and deep cultivation given effected a slight reduction in the number of run-offs, and in the quantities of water lost by run-off, when compared with the treatment on plot 3 which received shallow cultivation and also with treatment on plot 2 which received no cultivation, the difference was not statistically significant. Miller and Krusekopf [1932] found no benefit as a result of deep ploughing in checking the surface run-off of rain water.

The remaining treatment on plot 4 consisted of thorough and intensive cultivation, as in plots 7 and 8, and had in addition a *rabi* crop of *jowar* from

October to February. The total number of run-offs during the five years from the plot was 46 and the total quantity of water lost amounted to 22·92 in. Thus there was no apparent influence of the cultivation of a *jowar* crop on the rain-water run-off. This may be attributed to the fact that most of the rains were received before the sowing of the crop and only a small amount during the very early stage of the crop when the young seedlings could not in any way influence the run-off. Fig. 5 illustrates the comparative losses of water every year under different treatments.

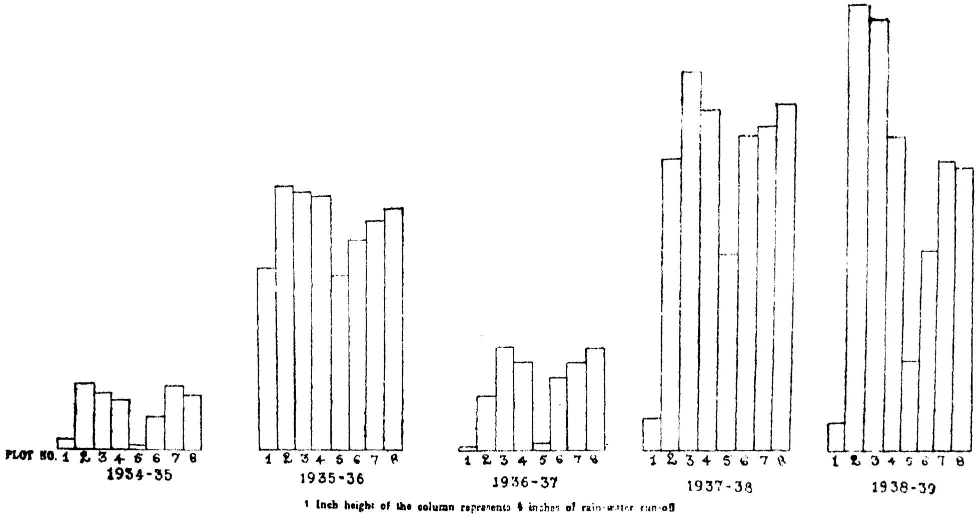


FIG. 5. Relative quantities of rain water in inches lost by run-off from plots under different treatments

[Plot 1, weeds preserved ; plot 2, weeds removed ; plot 3, harrowed only ; plot 4, *rabi* crop of *jowar* ; plot 5, scooped ; plot 6, *kharif* crop of *bajri* and *tur* ; plot 7, ploughed and harrowed ; plot 8, ploughed and harrowed with double length]

Thus, to sum up the results of the experimental work on the effect of the different treatments on rain-water run-off, it can be stated that: (1) There is some reducing effect resulting from deep cultivation on the number of run-offs and on the quantity of rain water lost by run-off as compared to the effects of shallow or no cultivation. The results of treatments on plots 2, 3 and 7 suggest the above conclusion. (2) The length of the plot does not affect the run-off materially as seen from the comparison of the results of treatments on plots 7 and 8. (3) The cultivation of *rabi jowar* also had no influence on the run-off. (4) The cultivation of a mixed crop of *bajri* and *tur* in the *kharif* season reduced the quantity of water lost by run-off. (5) The special cultural treatment of 'scooping' reduced both the number of run-offs and the total quantity of water lost by run-off. (6) The most effective treatment in controlling and reducing the rainfall run-off was found to be the conservation of the natural vegetation on the untouched surface of the soil.

(*B*) *The total annual rainfall, the number of days on which run-off occurred and the quantity of rain water lost by run-off during the experimental period of five years*

Having considered the effect of different cultural treatments and systems of cropping on the quantity of rain water lost by run-off in the preceding paragraphs, it will be interesting to see whether any relationship can be traced between the total annual rainfall and the number of days on which run-off occurred as well as the total quantity of rain water lost by run-off during the same period.

TABLE IX

Total annual rainfall, the number of days on which run-off took place and the total quantity of rain water lost by run-off

Year	Total rainfall during the year in inches	The number of days on which run-off occurred	The total quantity of rain water lost by run-off in inches
1934-35	21·15	5	1·24
1935-36	29·52	9	5·70
1936-37	15·92	5	2·22
1937-38	26·11	20	8·36
1938-39	37·14	15	9·51

The data presented in Table IX are for treatment 3, i.e. shallow cultivation by harrowing on plot 3. The data from this plot are selected for consideration as this treatment represents closely the usual cultivation followed by the cultivators in the tract.

Careful scrutiny of the figures in columns 2 and 3 would indicate that no relationship can be established between the total annual rainfall and the number of days on which run-off occurred during the year. This is illustrated by the fact that the year 1938-39, with the highest total rainfall (37·14-in.), was not the year which recorded the largest number of run-off days. On the other hand, the year 1937-38, with only 26·11 in. total rainfall, recorded the largest number of days on which run-off occurred. Similarly the total quantity of rain water lost by run-off during the year is not proportional to the total rainfall received during the same period. This can be clearly seen by comparison of the data for the year 1934-35 with those for 1936-37 and again the data for the year 1935-36 with those for 1937-38. Thus the number of days on which run-off occurred and the total quantity of water lost by run-off bear no definite proportional relationship to total annual rainfall. Other factors in this connection are considered later.

(C) *Monthly rainfall, number of days on which run-off occurred and the total rainfall run-off from month to month during the experimental period*

The average number of days upon which run-off occurred in each month is shown in Table X for the whole period of five years for the treatment on plot 3, i.e. treatment 3, viz. shallow cultivation by harrowing. It will be seen that the maximum number of days of run-off was recorded in the month of September with an average of 3·2. July stood second with 2·2 days of run-off and August third with 1·8. The month of June recorded 1·6 days of run-off followed by October with an average of one day of run-off. The remaining seven months together recorded only 1·2 days of run-off. The average quantity of water lost generally increased from June to September and rapidly decreased from October to December. The remaining months. except March, recorded no run-off. The quantity of water lost by run-off was much higher in September and was equal to the total quantity lost during the three months of June, July, and August. The differing effects on rainfall run-off of the early rainfall (June-August) and the later (September and October) can be seen from the detailed consideration of the data presented in Table X. Thus, in the year 1934-35, the month of July recorded 6·06 in. of rainfall and the month of September, 6·56 in. But there was only very slight run-off equal to 2 cents of rainfall in July, while in September a loss of 1·20 inches occurred on three occasions. Examples can be multiplied to show that there is no exact relationship between the monthly rainfall and the quantity of rain water lost by run-off during the month. Detailed considerations of the experimental data for five years indicate that, for a given slope and type of soil, the most important factors that influence rainfall run-off appear to be : (1) the intensity of individual showers and (2) the moisture-status of the soil previous to the rainfall resulting in run-off. Both these factors are considered in detail in Table X.

(D) *Intensity of showers and rainfall causing run-off*

Appendix I-*a* shows the rainfall recorded on all rainy days in each month. The figures representing rainfalls that caused surface run-off from any of the experimental plots have been shown in italics. The data for all the five years of the experiments have been included in that table. In addition, the rainfalls have been grouped into four classes indicating varying intensities according to the quantity of rainfall received during a day or 24 hours. These data have been summarized in Table XI, which gives the total number of rainfalls in each class for each year and the number of rainfalls in each class which caused surface run-off.

It can be seen from Table XI that the total number of rainy days was 218 during the whole period of five years. Out of this total 55, or nearly 25 per cent of the total number, caused surface run-off. Only nine, or nearly 4 per cent of the total number, exceeded 2 inches of rainfall. Twenty-five, or 11·4 per cent varied from 1 in. to 2 in. Forty, or 18·3 per cent, varied from ½ in. to 1 in., while the remaining 144, or nearly 66 per cent, represent less than ½ in. rainfall in a day. Detailed examination of these data as presented in Table XI reveals an interesting relationship between the intensity of rainfall and the occasions of rainfall run-off.

TABLE X

***Monthly distribution of rainfall**, the number of days of rainfall run-off, and the quantity of water lost by run-off*

(Plot 3)

Month	1934-35			1935-36			1936-37			1937-38			1938-39			Average of 5 years		
	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches
June	0·59	...	...	3·54	1	0·05	2·43	...	...	1·92	2	0·69	8·45	5	2·56	3·38	1·6	0·66
July	6·06	1	0·02	2·26	1	0·01	1·62	1	0·04	3·65	3	0·23	11·59	5	2·39	5·07	2·2	0·54
August	5·33	2	0·02	0·84	6	4·34	1·10	...	...	1·53	1	0·08	4·53	...	...	4·56	1·8	0·89
September	6·56	3	1·20	3·44	...	...	3·12	2	0·76	8·96	6	3·93	11·02	5	4·56	6·62	3·2	2·09
October	0·28	...	...	6·39	1	1·30	0·47	...	...	5·12	4	1·78	1·86	...	...	2·66	1·0	0·61
November	1·62	...	...	0·01	...	...	3·75	2	1·42	...	...	...	...	...	...	1·08	0·4	0·28
December	...	...	...	0·56	...	...	0·05	...	...	2·08	3	1·07	...	...	...	0·54	0·6	0·22
January	0·19	...	...	...	...	...	...	...	...	...	..	...	...	...	...	0·4	...	...
February	...	...	...	0·73	...	...	0·23	...	...	...	...	...	...	...	...	0·19	...	...
March	...	...	...	0·36	...	...	0·75	...	...	2·21	1	0·58	...	...	...	0·66	0·2	0 11
April	0·41	...	...	0·55	...	...	2·40	...	...	0·23	...	...	0·49	...	...	0·84	...	...
May	0·11	...	...	0·74	...	...	...	...	...	0·41	...	...	...	...	...	0·25	...	...
Total . .	21·15	6	1·24	29·42	9	5·70	15·92	5	2·22	26·11	20	8·36	37·14	15	9·51	25·96	11	5·40

in the annual rainfall, difference in monthly distribution of rainfall and variation in the intensity of showers. The same data are calculated as per cent of the total annual rainfall and are given in Table XIII.

TABLE XIII

Rainfall lost by run-off as per cent of the annual total for 1934-39

Year	Rainfall in inches	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35	21·15	0·99	6·47	5·86	5·15	0·09	3·21	6·70	5·70
1935-36 . . .	29·52	13·60	19·60	19·32	18·84	12·90	15·64	17·00	17·90
1936-37 . . .	15·92	0·43	6·60	13·94	11·85	1·19	9·92	12·12	13·70
1937-38 . . .	26·11	2·48	24·35	32·01	28·66	16·54	26·77	27·34	29·64
1938-39 . . .	37·14	1·72	26·49	25·60	18·63	5·41	11·86	17·24	16·92
Average of five years .	25·96	3·44	15·50	18·34	16·61	7·22	13·48	16·08	16·71

The examination of these figures indicates fairly consistent behaviour of most of the plots under different treatments in the majority of seasons. The average results of five years show that the percentage losses of rain water in two treatments, viz. that of untouched vegetative cover (plot 1) and of 'scooping' (plot 5), are distinctly lower, viz. 3·44 and 7·22 per cent of the average total annual rainfall although there is considerable seasonal variation. In the remaining six treatments, the average percentage losses vary from 13·48 to 18·34. The lower figure was obtained with the treatment of *bajri* and *tur* cropping (plot 6) and the largest for the treatment of mere shallow cultivation without any crop (plot 3). Miller and Krusekopf [1932] in their experiments found the run-off to vary from 12 to 30·7 per cent of the total rainfall. The percentage losses found at Sholapur appear therefore to be comparatively smaller than those recorded in the U. S. A.

(*G*) *Loss of rain water by run-off as per cent of the rainfall causing run-off*

It has already been shown that all rainfalls are not capable of producing run-off. Most of the run-offs are produced by rains of more than ½ in. in intensity. As the important crop in this tract (*jowar*) is grown in the *rabi* season on moisture resulting from the rainfalls during the early monsoon and conserved in the soil, only such of the rainfalls as can penetrate down into the lower layers of the soil can be considered as useful from the point of view of *rabi* cultivation. It has been observed that rainfalls of more than one inch received in 24 hours are of this type and nearly 80 per cent of such rainfalls usually produce run-off. Therefore, if the amounts of the rain water lost by run-off are calculated as percentages of the rainfalls causing run-off, the figures obtained indicate that a very high proportion of the agriculturally useful rainfalls are lost by run-off. Calculations on these lines, along with their deviations, are given in Table XIV.

Examination of the figures in Table XIV indicates more consistent behaviour as regards run-off of most of the plots in the majority of years. It can be seen that only two plots, viz. 1 and 5, which had the lower run-offs, show wide fluctuations. With the remaining plots under different treatments, the annual figure of run-off in four years out of five shows a close agreement with the average figure computed for the total period of five years. In the first year of the experiment only, the results were much lower than the average figure on account of very favourable distribution of rainfall during that year. The average proportion of the water lost to the total rainfall causing run-off under most of the treatments is very high varying from 26 to 38 per cent in the six cultural treatments used in the experiments. This proportion in some years and under some treatments exceeded 44 per cent. This high loss of useful rainfall assists in explaining the occurrence of crop failures even in years with a total average rainfall.

TABLE XIV

Rainfall lost by run-off as per cent of the total rainfall causing run-off

Year	Total rain-fall causing run-off	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35 . . .	8·11	2·59	16·96	15·31	13·45	0·25	8·39	17·53	14·94
1935-36 . . .	14·77	27·21	39·26	38·59	37·58	25·93	31·37	33·98	35·95
1936-37 . . .	5·93	1·18	17·87	37·44	31·87	13·20	26·65	32·55	36·93
1937-38 . . .	19·38	3·35	32·82	43·13	38·54	22·29	36·07	37·10	39·93
1938-39 . . .	22·30	2·88	44·32	42·83	31·17	9·05	19·86	28·87	28·37
Average . .	14·09	7·93	34·65	38·34	32·51	14·71	25·93	31·09	32·27
	±3·15	±4·96	±5·97	±5·36	±4·62	±5·28	±4·88	±1·79	±4·53

XIII. LOSS OF SOLUBLE SALTS FROM SOILS IN RUF-OFF WATER

The quantities of the fertility elements removed in solution by run-off waters were determined in some years. The total salts and lime thus lost in run-off waters were determined in all years after every run-off. These data are given in Appendices I-*c* and I-*d*. Considering the data for plot 4, i.e. treatment 4, viz. cultivation of *rabi jowar* after intensive preparatory cultivation, the total soluble salts lost in a year show a variation of from 26·06 lb. to 234 lb. per acre during the five years. Soluble lime forms quite a substantial proportion of the total salt. This can be seen from data in Appendix I-*d*. The quantity of lime removed has varied, indifferent years, from 9·22 lb. to 91·18 lb. per acre, showing that it forms nearly 35-39 per cent of the total soluble salts.

The nitrogen content of all the run-off waters, both as nitric nitrogen and as ammoniacal nitrogen, was also determined in three seasons. The total quantity of nitrogen thus removed in solution was found to be very small in each of these years. The average quantity lost every year during this period varied in different plots from 0·13 lb. to 0·53 lb. per acre. The nitric and the ammoniacal forms of nitrogen were found in nearly equal proportions. The nitrogen received in the rain water every year was separately determined and deducted from the nitrogen obtained from the run-off waters.

Phosphoric acid removed in solution in the run-off waters was determined during 1936. The total quantity lost during the whole year was found to be very low, being only about ½ lb. per acre from plot 4, i.e. *rabi jowar* cultivation (treatment 4).

If the quantities of nitrogen and phosphoric acid lost in solution in run-off water are compared with similar figures for other countries, the Sholapur figures are found to be very low indeed. The quantities of phosphoric acid lost in similar experiments at the Missouri Experiment Station are much higher, viz. 47 lb. per acre in the uncultivated plot as compared to less than ½ lb. at Sholapur. Even the nitric nitrogen lost at Missouri exceeded 6 lb. per acre in the uncultivated plot. These low values at Sholapur are mainly due to the low initial fertility of the Sholapur soils, with regard to both nitrogen and phosphoric acid.

XIV. RESULTS OF SOIL EROSION EXPERIMENTS AT SHOLAPUR

The loss of rain water by surface run-off is no doubt a considerable factor contributing towards crop failures in the Deccan tracts of precarious rainfall, but such loss of water is only temporary, being restricted in its effects to the season only. The con-comitant loss of soil that takes place with every run-off of rain water causes a serious permanent and accumulative damage to the land. The soil lost is lost for ever. The same factors which influence the run-off of rain water also influence soil erosion. Thus the cultivation given to the land, the total annual rainfall, the intensity of successive showers, the moisture-status of the soil, all have a direct influence on soil erosion as on rainfall run-off. It is not therefore necessary to consider these factors again in detail. The experiments to determine the losses of rain water by run-off, described hitherto, were simultaneously utilized to determine the quantities of silt lost under different methods of cultivation or treatment. The exact quantities of silt lost during the five years from the plots under varying treatments are given in Table XV.

(A) Effect of varying plot treatments on soil erosion

When the quantities of soil carried by run-off water from the eight plots under different treatments are considered, as shown in the data in Table XVI, it can be seen that each plot shows a similar trend from year to year. Thus, plot 1, where the natural vegetation of grasses and weeds were preserved, showed the smallest degree of soil erosion in each year. Plot 5, which received the special cultural treatment of 'scooping', stood next lowest though it lost comparatively higher quantities of silt when compared with plot 1. Plot 2, which was uncultivated but from which the weeds were removed by cutting close to the surface, stood third lowest in the total quantity of silt lost during the experimental period of five years. Plot 6, which had a mixed crop of *bajri* and *tur* every year, ranked fourth in its effect on checking soil erosion. Plot 3, which received only shallow cultivation every year and carried no crop, is next in order. Plot 8 had double the length and hence double the area as compared to the rest of the plots. But, when calculated on the basis of area, the quantity of silt removed was lower than that of plot 7 with which it is otherwise comparable. Plot 7, with thorough and intensive cultivation but with no crop, lost nearly 35 per cent more silt than plot 3 with shallow cltivation. Plot 4, with thorough and intensive cultivation and carrying a crop of *jowar* during the *rabi* season, lost the highest quantity of silt during the period of five years, probably on account of the coincidence of the interculturing operations given to the plot and the occurrence of some of the heavy rainfall showers. The surface 2-inch layer of

TABLE XV

Quantity of silt in pounds carried by run-off water from each plot

Year	Total rainfall during the year (inches)	Rainfall causing run-off (inches)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
			Retention of natural vegetation	Natural vegetation removed by cutting	Shallow cultivation by harrowing	Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*	'Scooping' of the surface soil after thorough cultivation	Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture	Thorough and intensive cultivation by ploughing and harrowing	Thorough and intensive cultivation as in plot 7 with double length
1934-35	21·15	8·11	0·73	25·61	14·28	27·83	0·20	28·66	37·02	2·29
1935-36	29·52	14·77	16·24	698·88	1,679·16	3,235·48	1,099·09	1,232·28	2,654·96	2,591·12
1936-37	15·92	5·93	2·02	30·56	81·87	120·76	9·86	230·38	493·85	63·45
1937-33	26·11	19·38	6·44	2,459·52	3,185·28	2,727·24	1,411·76	3,311·56	3,291·23	6,895·09
1938-39	37·14	22·30	4·62	572·38	503·02	933·32	379·90	394·02	845·77	1,562·57
Total .	129·84	70·49	30·05	3,786·95	5,463·61	7,044·63	2,900·81	5,196·90	7,322·83	11,114·52

the soil became loose and dry as a result of these interculturing operations and a large quantity of soil from this layer was removed with the run-off water after the heavy showers of October, November, or December.

In Table XVI, the soil erosion data for five years are given as tons of silt lost per acre. The seriousness of this problem of soil erosion is brought out very markedly by these figures. Natural vegetation appears to be the most effective means of checking soil erosion. The special treatment of ' scooping ', though effective in reducing erosion, still resulted in a loss of nearly 100 times the quantity of silt lost from plot 1 with natural vegetation cover. Shallow or deep cultivation proved even more harmful and resulted in the loss of still more silt as can be seen by comparing the data of plots 2, 3 and 7. Shallow cultivation resulted in an increased loss of silt by about 40 per cent, and deeper cultivation by about 90 per cent as compared with the loss of silt from plot 2 with no cultivation. Increase in the length of the plot did not increase the extent of erosion, as may be seen by comparing the results of plots 8 and 7. In fact, there seems to be a tendency to deposition of suspended silt when the distance over which the run-off water has to travel increases. The results obtained by Duley and Ackerman [1934] on this point were not conclusive. But, in general, they found that light showers caused more erosion on shorter plots, while heavy showers caused more erosion on longer plots. Fig. 6 illustrates the comparative quantities of silt lost during the five years under different treatments.

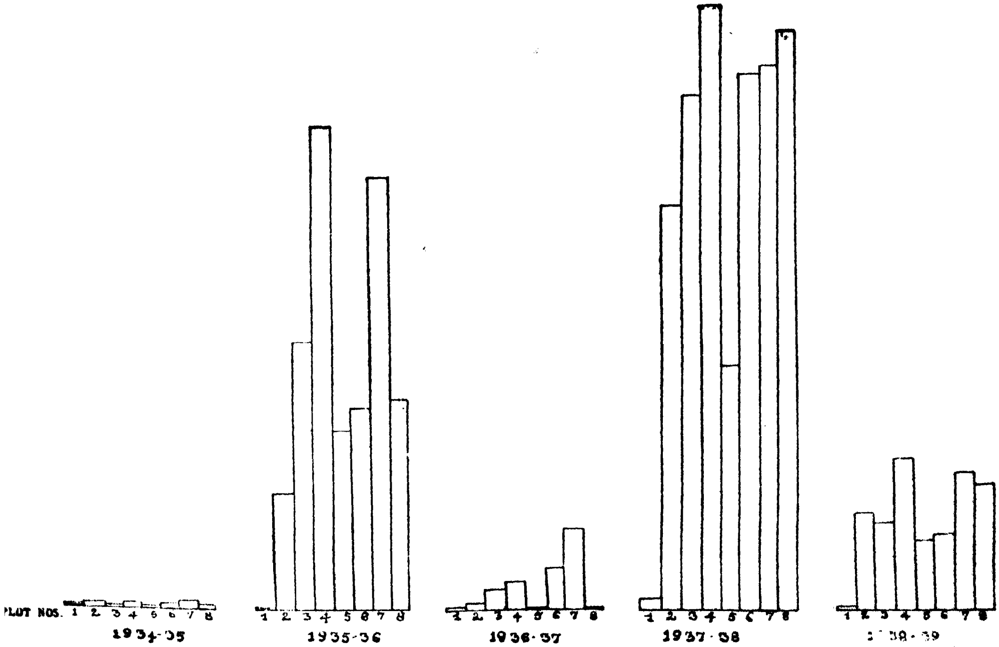


FIG. 6. Relative quantities of soil lost by erosion from plots under different treatments

[Plot 1, weeds preserved ; plot 2, weeds removed ; plot 3, harrowed only ; plot 4, *rabi* crop of *jowar* ; plot 5, scooped ; plot 6, *kharif* crop of *bajri* and *tur* ; plot 7, ploughed and harrowed ; plot 8, ploughed and harrowed with double length]

(1 inch height of col. = 40 tons.)

TABLE XVI

Silt carried in run-off water calculated as tons per acre from plots under different treatments during five years of experiments

Year	Total rainfall during the year (inches)	Rainfall causing run-off	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35	21·15	8·11	0·026	0·916	0·510	0·993	0·007	1·023	1·322	0·576
1935-36	29·52	14·73	0·580	24·960	59·970	115·660	39·250	44·010	94·820	46·270
1936-37	15·92	5·93	0·072	1·092	2·924	4·310	0·352	8·220	17·630	1·13
1937-38	26·11	19·38	0·230	87·840	113·760	133·480	50·420	118·270	117·540	127·680
1938-39	37·14	22·30	0·165	20·442	17·960	33·330	13·570	14·070	30·210	27·900
Total during five years .	129·84	70·45	1·073	135·250	195·124	287·773	103·599	185·543	261·522	203·556
Average of five years .	25·97	14·09	0·215	27·05	39·02	57·55	20·71	37·12	52·30	40·71
Number of years required to erode 8 inches of cultivated layer of surface soil			4,146·0	22·92	22·84	15·48	43·01	24·01	17·04	21·90

On the basis of the data of five years' experimental period, the average loss of silt per year from the plot cultivated with *rabi jowar*, i.e. plot 4 was 57·55 tons per acre. This indicates that nearly ½ in. of the surface layer of soil is liable to be lost by erosion each year. If the weight of the first acre-foot surface soil is taken as three million pounds, the cultivated surface layer of 8 in. could be lost in about 15½ years if no attempt be made to check erosion by proper levelling, terracing, or bunding of the fields. This rate of erosion seems to be much greater than that found elsewhere, as in the U. S. A. It was found by Duley and Miller [1923] in their experiments in the U. S. A. that it would take 28 years to erode the cultivated surface layer of 7 in. The slope of their experimental plot was much greater, viz. 3·75 per cent, than the moderate slope of 1·18 per cent of the Sholapur experimental plots. The average rainfall at the American experimental station was also higher, viz. 35·87 in. instead of 25·96 in. at the Sholapur Experimental Station.

Accordingly tropical conditions seem to be more favourable for heavy erosion. The rate of erosion under Deccan conditions is extremely high, as may be seen by examination of the figures in the bottom line of Table XVI. The surface 8-in. layer is taken as the cultivated layer of the soil and is known to weigh about 2 million pounds per acre. From the average quantity of soil lost per year under each plot treatment, the number of years required to erode completely the cultivable layer of the surface soil has been calculated. As already pointed out, plot 4, which represents the normal cultivation of *rabi jowar* followed by a few good cultivators in this tract, shows that the surface layer is liable to be lost in an extraordinarily short period. Other methods of cultivation tried in these experiments also indicate similar high rates of erosion, requiring only 17-43 years for the removal of the cutivated layer of the surface soil. The only effective treatment for checking soil erosion was the preservation of the natural vegetation on the surface soil as represented by the treatment in plot 1.

(*B*) *Relationship between total annual rainfall and soil erosion*

The total annual rainfall during the five years during which the experimental work has been in progress has varied from 15·92 to 37·14 inches, while the total rainfall causing run-off and producing soil erosion has varied from 8·39 to 22·30 in. in the five years. It has been already shown that the total run-off is not always proportionate to the total rainfall of the year. The intensity of the showers and the moisture-status of the soil have more influence on the extent of run-off than the total rainfall. The same finding holds good in the case of soil erosion. The year 1936-37, which recorded the lowest rainfall (Tables XV and XVI), was not the year of the lowest soil erosion. In the same way the year 1938-39 with the highest total rainfall was not the year of the highest soil erosion. The year 1937-38 with only an average annual rainfall had the highest number of rainfalls causing run-off and erosion. This year, therefore, proved most damaging in that it gave the highest erosion.

(*C*) *Effect of the intensity of showers on soil erosion*

Out of the total amount of soil lost during each year by erosion, the greater proportion was lost during one to three intensive rainfalls only. The term 'intensive' implies either a high total rainfall or rainfall that is received as stormy showers, within a short period of time, e.g. 1-2 hours. Thus, in the first year only one rainfall on 7 September amounting to 2·67 in., received overnight, resulted in the loss of 89 per cent of the total silt removed during the year from plot 4 (Appendix I-*b*). In the second year, out of nine rainfalls causing erosion, two only accounted for 90 per cent of the total soil lost by erosion in that year. In the third year, two rainfalls out of five were responsible for the greater part of soil loss. In the fourth year, out of 20 rainfalls, three intensive falls only resulted in the loss of nearly 80-90 per cent of the total silt lost during the whole year. In the fifth year again, only two rainfalls out of 15 falls resulting in erosion caused the greater proportion of soil loss.

Thus, out of the large number of rainfalls (55) causing erosion (Table XI) during the five years, only 10 rainfalls could be termed intensive and these resulted in the loss of 80-90 per cent of the total soil lost from the seven plots under different treatments, during the experimental period of five years, as shown in Table XVII. In this respect, the data regarding run-off of rain water alone are somewhat different. In the case of run-offs, a greater number of total rainfalls is required to make up 80-90 per cent of the total loss of rain water. This indicates that the intensity of a shower has a greater influence on erosion than on run-off.

TABLE XVII

High proportion of silt lost in five years by ten intensive rainfalls

Plot No.	Treatment	Total pounds of soil lost during the 5 years	Total pounds of soil lost during the 10 intensive rainfalls	Percentage of total soil lost by ten rainfalls
1	Retention of vegetation	30·05	16·08	53·52
2	Removal of vegetation	3787·01	3437·61	91·07
3	Shallow cultivation	5463·61	5055·45	92·55
4	Cultivation of *rabi jowar*	8054·83	7367·47	91·47
5	'Scooping'	2900·72	2601·96	89·71
6	Cultivation of *kharif bajri* and *tur* . . .	5196·90	4206·98	80·93
7	Thorough and intensive cultivation . . .	7422·83	6547·24	88·22
8	Thorough cultivation and double length . .	11144·52	10234·37	91·83

(*D*) *Moisture-status of the soil previous to soil erosion, and its effect on soil erosion*

As the type of soil erosion considered here is dependent upon the run-off of rain water, all the factors that affect rainfall run-off also affect soil erosion. The moisture-status of the soil, previous to rainfalls causing run-off of rain-water has been shown to influence the quantity of rain water lost by such run-off. A similar influence of this factor on soil erosion can be seen from the detailed data of soil lost by erosion given in Appendix I-*b*. Comparatively greater losses of soil take place from erosion after the surface soil attains moisture-saturation which does not usually happen before August or September.

(*E*) *Relative proportion of water and silt lost by run-off and erosion*

It will be interesting to examine whether any relationship exists between the quantity of water lost by a run-off and the amount of silt carried away by such run-off water. The comparative quantities of water and silt lost in pounds from each plot during the five years of experiments are given in Table XVIII. In the last line of this table, the ratio of the total water lost to the total soil removed is shown for the whole period of five years. It may be said in general, that the greater the amount of water lost, the greater is the amount of silt removed. But the ratio of losses of water to losses of soil differs widely, e.g. from 7·96 to 520·8, according to the varied treatments given to the plots. The plot with vegetation cover gives the widest ratio of 520·8 and differs entirely in this respect from the other treatments. The remaining seven treatments show a ratio ranging from 7·96 to 18·07. This would indicate that the capacity of run-off water to remove soil under the experimental conditions at Sholapur is very high when compared with the results obtained in similar experiments conducted in the U. S. A. The curve showing the relation of water lost to soil eroded shows a general relationship between run-off and erosion under different treatments (Fig. 7). Under tropical and arid conditions, the rate of soil erosion appears to be very high. It may be pointed out that the soil type in the present experiment cannot be considered as erodible according to Middleton as it belongs to the heavy clay type but the results obtained in the experiments at Sholapur agree with the views of Bennett who considers sticky soils with high swelling and shrinkage capacity as very erodible.

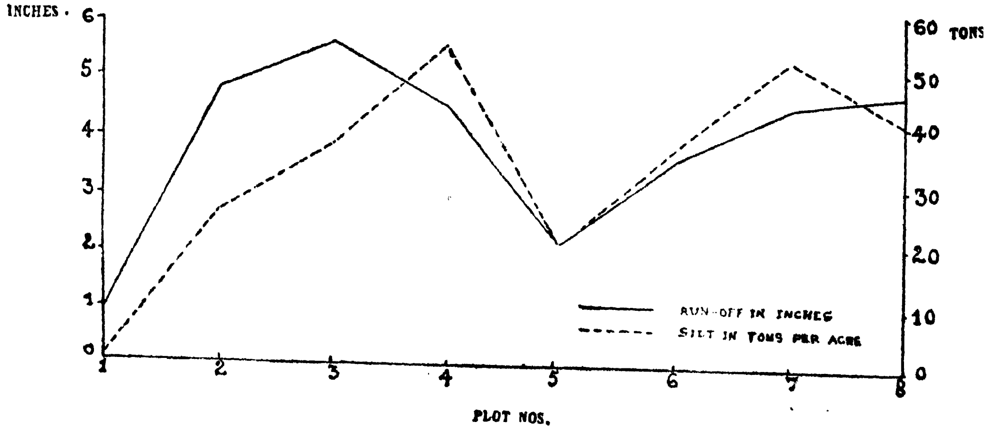


FIG. 7. Relative proportion of water and silt lost by run-off and erosion under different treatments

[Plot 1, weeds preserved ; plot 2, weeds removed ; plot 3, harrowed only ; plot 4, *rabi* crop of *jowar* ; plot 5, scooped ; plot 6, *kharif* crop of *bajri* and *tur* ; plot 7, ploughed and harrowed ; plot 8, ploughed and harrowed with double length]

TABLE XVIII

Comparative quantities of water lost by run-off and silt carried in pounds per acre

Year	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt
1934-35	588	0·7	3,336	26	3,472	14	56	28	1,904	0·2	1,904	29	3,976	37	6,776	32
1935-36	11,256	16·3	16,240	699	15,960	1,679	15,540	3,235	10,724	1,099	12,936	1,232	14,056	2,655	29,736	2,591
1936-37	196	2·0	2,968	31	6,216	82	5,292	121	532	9·9	4,424	230	5,402	494	12,264	63
1937-38	1,820	6·4	17,808	960	23,408	3,185	20,916	3,737	12,096	1,412	19,572	3,312	19,992	3,291	43,344	6,896
1938-39	1,792	4·6	27,552	572	26,628	503	19,373	933	5,628	380	1,234	846	17,948	845	35,280	1,563
Total for five years. (From 1 June 1934 to 31 May 1939)	15,652	30·0	68,404	4,288	75,684	5,463	61,177	8,054	30,884	2,901	40,070	5,649	61,374	7,322	1,27,400	11,144
Pounds of water required to carry 1 lb. of silt in the run-off water	520·8		18·06		13·86		7·96		10·01		9·85		8·27		11·44	

Although the ratios of soil removed to rainfall run-off for the whole period of five years under seven different treatments show a limited variation, the actual day-to-day ratios have been found to show extraordinary variation. A litre of water could carry silt in suspension varying from less than 1 gm. to more than 400 gm. on different days, depending upon various factors, such as the total quantity of rainfall, intensity of showers, and the moisture-status of the soil previous to run-off.

(*F*) *Effects of soil erosion*

(*a*) *Increase in the slope of land*

Before the commencement of the experiments at Sholapur in 1934, accurate levels of the experimental plots were determined by a dumpy level along three lines in each plot at every 5 ft. distance. From the difference between the average levels at the top and at the bottom, the percentage slope of each plot was determined. The average slope for all the plots was 1·18 per cent or a fall of 1 in 85, in 1934. At the end of the period of five years, levels were again determined by the same method in all plots. The average slope for all plots was found to have increased to 1·68 per cent or a fall of 1 in 60, in 1939.

Thus, the accumulated loss of soil from the plots due to erosion during a period of five years had resulted in increasing appreciably the original slope of the plots. Such an increase in gradient is likely to accelerate the rate of run-off and also of erosion. This change in level is illustrated in the vertical section of plot 4, along the length, in Fig. 8.

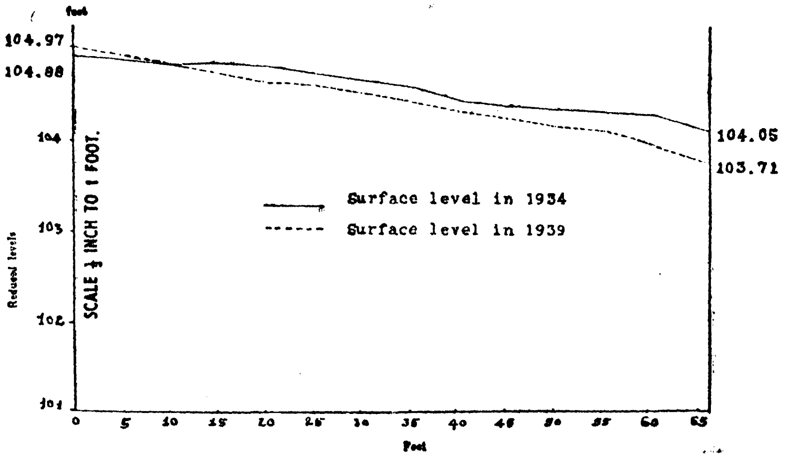


FIG. 8. Change in gradient of plot 4 by soil erosion

(*b*) *Loss of fertility elements*

The soil lost by erosion after each rain-fall resulting in run-off of rain water from the eight different plots was collected for a period of three years, viz. 1934-35, 1935-36 and 1937-38. A composite sample was prepared each year for each plot by taking a proportionate quantity from each bulk of eroded material and these samples were analysed for total nitrogen.

TABLE XIX

Percentage of nitrogen in silt obtained in run-off waters and pounds of nitrogen lost per acre from different treatments

Plot No.	1934-35		1935-36		1937-38		Average for 3 years	
	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre
1. Retention of vegetation	0·133	0·07	0·109	1·41	...	...	0·082	0·74
2. Removal of vegetation	0·059	1·21	0·047	26·27	0·051	107·51	0·052	44·99
3. Shallow cultivation	0·069	0·79	0·050	67·26	0·056	142·70	0·058	70·21
4. Cultivation of *rabi jowar*.	0·052	1·15	0·049	126·95	0·055	184·47	0·052	104·19
5. 'Scooping'	0·068	0·01	0·042	36·92	0·052	58·73	0·054	32·83
6. Cultivation of a *kharif crop* of *bajri* and *tur*	0·046	1·05	0·050	49·28	0·062	175·98	0·053	75·44
7. Thorough cultivation	0·052	1·54	0·046	97·70	0·059	155·34	0·052	84·86
8. Thorough cultivation with double length	0·087	1·15	0·056	58·04	0·070	200·20	0·071	86·46

TABLE XX

Chemical analysis of silt lost from surface run-off plots during 1935-36

(Expressed on per cent dry matter)

Plot No.	Loss on ignition	Sand	Fe_2O_3	Al_2O_3 and TiO_2	CaO	MgO	K_2O	P_2O_5	Nitrogen	Stone per cent on original
1. Retention of vegetation	10·51	55·18	10·10	12·95	1·80	1·23	0·59	0·06	0·109	6·65
2. Removal of vegetation	7·35	55·47	10·73	11·10	4·69	1·38	0·47	0·05	0·047	23·42
3. Shallow cultivation	7·23	55·76	10·88	12·60	3·43	1·58	0·48	0·06	0·050	12·53
4. Cultivation of *rabi jowar*	7·30	54·59	10·66	13·42	3·28	1·64	0·49	0·05	0·049	15·09
5. 'Scooping'	7·71	56·46	11·21	12·07	3·59	1·54	0·53	0·05	0·042	7·90
6. Cultivation of *kharif bajri* and *tur*	6·83	56·66	11·90	12·57	2·72	1·33	0·51	0·06	0·050	7·38
7. Thorough cultivation	7·73	56·46	11·53	12·12	2·80	1·24	0·57	0·06	0·046	11·16
8. Thorough cultivation with double length	8·02	59·53	11·69	12·55	1·61	1·32	0·50	0·06	0·056	3·43

The percentage of nitrogen present in the eroded soils obtained each year was distinctly higher than that found in the original soil which was only 0·039 per cent. The presence of vegetation on plot 1 naturally increased the nitrogen content of the soil from that plot. Table XIX shows the percentage nitrogen in soil and estimated quantities of nitrogen lost per acre under different experimental treatments during the three years. It may be seen that the quantity of nitrogen lost has varied according to the quantity of silt carried off by the run-off water from the plots under different treatments.

The average annual loss of nitrogen per acre during the three years was found to be very high from all cultivated plots, whether with or without crops, although that loss varied considerably from year to year. Only in the case of the plot with natural vegetation-cover, was the loss very low due to low loss of soil. The average loss of nitrogen per year is equivalent to nitrogen removed by 8 or 10 crops of *jowar* or *bajri* when cultivated on this type of soil in this tract. These losses are higher than the results of similar estimation made by the American workers [Miller and Krusekopf, 1932].

Complete chemical analysis of the eroded soils from different plots was made in the year 1935-36, by the method of hydrochloric acid digestion. The results of these analyses indicated that soils removed were richer in important fertility constituents than the original soil (Table XX).

XV SUMMARY OF THE EXPERIMENTS AT SHOLAPUR

RAINFALL RUN-OFF

1. Experiments conducted at Sholapur for a period of five years from 1934-35 to 1938-39, to determine the loss of rain water by surface run-off, are described.

2. The soil type upon which these experiments were conducted belongs to the Chernozem group derived from the Deccan trap. It has a high clay content and is rich in potash and lime but comparatively poor in nitrogen and phosphoric acid.

3. Eight unit plots were laid down under the following treatments* respectively :—

(1) Preservation of natural vegetation—no crop.
(2) Natural vegetation above soil surface level removed by cutting—no crop.
(3) Shallow cultivation by harrowing—no crop.
(4) Thorough and intensive cultivation with subsequent cultivation of *rabi jowar* crop.
(5) Special cultural treatment with a ' scooper '—no crop.
(6) Thorough and intensive cultivation followed by a mixed crop of *bajri* and *tur*.
(7) Thorough and intensive cultivation only—no crop.
(8) Thorough and intensive cultivation on a plot length double that of plots 1 to 7—no crop.

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*It will be noted that crop cultivation was carried out on plots 4 and 6 only. Intensive cultivation implies deep ploughing in the hot weather season followed by several harrowings during the monsoon period and several interculturings during the normal period of crop growth. Ploughing was done across the slope of the plots.

4. The shape of the plots was a rectangle having the dimensions 66 ft. length × 8·25 ft. width in the first seven plots and 132 ft. length × 8·25 ft. width in the eighth, with an average one way slope of 1·18 per cent along the length of the plots.

5. The average annual rainfall during the experimental period of five years corresponded closely with the average annual precipitation in the tract during the past 25 years. The monthly distribution of rainfall, however, showed some deviation from the average. The average number of rainy days* per year during the experimental period of five years and the past 25-years period was also similar.

6. The annual number of rainfalls causing run-off of rain water during the five-year period varied from 5 to 20, the annual average for the whole period being 11.

7. These run-offs of rain water were mostly restricted to the period from June to October. The month of September recorded the highest number. The average annual loss of water by run-off varied from 1·12 in. to 5·40 in. under the different treatments under experiment.

8. All the rainfalls received during the experimental period of five years have been grouped into four classes according to their intensities, i.e. according to the quantity of rainfall received during a day, i.e. 24 hours. It is found that all rainfalls exceeding 2 in. during a day resulted in run-off of rain water. There were nine such rainfalls during the experimental period of five years. The total number of rainfalls in class 2, i.e. rainfalls varying from 1 in. to 2 in. during a day, was 25 and, of these, 20 rainfalls or 80 per cent of the total caused run-off of rain water. There were 40 rainfalls varying from ½ in. to 1 in. received in a day in class 3. Of these, 14 rainfalls or 35 per cent caused rainfall run-off. The last class consisted of 144 rainfalls of less than ½ in. recorded during a day. Of these, only 12 rainfalls or 8 per cent of the total of this class resulted in run-off of rain water.

9. The previous moisture-status of the soil influenced the occurrence and extent of run-off very greatly.

10. The number of rainfall run-offs appeared to depend more on the number of heavy showers received during the year rather than on the total annual rainfall. Rainfalls exceeding 1 in. received during a day, i.e. 24 hours, are reckoned as heavy showers.

11. The treatments which appear to have the greatest effect in checking or reducing the run-off of rain water are :—

(1) the preservation of the natural vegetation,

(2) the special treatment of 'scooping',

(3) the presence of a mixed crop of *bajri* and *tur* after intensive cultivation.

12. Thorough and intensive cultivation alone showed a more restricting influence on the number of rainfall run-offs and on the quantity of water lost by such run-offs, when compared with shallow cultivation or no cultivation.

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* A 'rainy' day indicates a day of 24 hours upon which 10 cents or more of rainfall were received.

13. The doubling of the length of the plot, or the growing of a *rabi* crop of *jowar*, showed no noticeable difference in influencing the number of rainfall run-offs or the quantity of water lost by such run-offs.

14. Appreciable quantities of soluble salts are removed from soils in rainfall run-off, lime forming a considerable proportion of such losses. The loss of nitrogen and phosphoric acid in solution was however found to be very small.

SOIL EROSION

I. The extent of soil erosion was determined annually by measuring the quantities of soil carried away by run-off of rain water from the same eight unit experimental plots under different treatments (para. 3 above) upon which the run-offs of rain water were determined during the five years of the experiments.

II. The same eight different plot treatments as mentioned in para. 3 above were compared to see their comparative effect on soil erosion.

III. The annual average loss of soil by erosion varied from 0·215 tons per acre in plot 1, i.e. the plot with natural vegetation preserved, to 57·55 tons per acre in plot 4, i.e. the plot with the *rabi* crop of *jowar* following intensive hot weather cultivation. The special treatment of 'scooping', i.e. plot 5, gave an average loss of 20·71 tons per acre, showing some checking effect of this treatment on soil erosion. Plot 2 with vegetation removed and without cultivation showed less erosion, viz. 27·05 tons per acre, than plots with shallow and intensive cultivation, i.e. plots 3 and 7 respectively, which showed 39·02 and 52·30 tons per acre respectively. The standing crop of *bajri* and *tur* mixture after intensive hot weather cultivation, i.e. plot 6, had some effect in reducing soil erosion, this plot giving an average loss of 37·12 tons per acre. Increase of the length of the plot, i.e. plot 8, showed an average loss of 40·71 tons per acre, and the tendency to the deposition of silt along the plot surface reducing the erosion to some extent.

IV. Except on the plot with natural vegetation preserved, i.e. plot 1, the average quantity of run-off water required to remove 1 lb. of soil showed a variation of from 0·796 to 1·806 gallons under different treatments. These figures indicate an extremely high rate of erosion under the Deccan conditions.

V. The average number of occasions upon which soil erosion was found to take place was 11 per annum. Of these, only two per year, on an average, are responsible for causing 80-90 per cent of the total loss of silt by erosion during the year. The rainfall on these two occasions was very heavy and intensive, usually more than 2 in. received in a few hours on an already saturated soil surface.

VI. As a result of soil erosion during five years, the original slope of the plots was found to have appreciably increased.

VII. The soil removed by rainfall erosion is richer in all plant food ingredients than the original soil. The average quantity of nitrogen lost in such eroded soil in a year is equivalent to that removed by 8-10 *jowar* or *bajri* crops.

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REFERENCES

Bennett, H. H. (1931). *J. Amer. Soc. Agron.* **23,** 434-54

Christiansen-Weniger, F. (1934). *Principles of crop cultivation in Turkey*; Leipzig (Quoted by Jacks and Whyte, 1938)

Conner, A. B., Dickson, R. E. and Scoates, D. (1930). *Texas. Agric. Expt. Sta. Bull.* **411**

Dickson, R. S. (1929). *J. Amer. Soc. Agron.* **21,** 415-22

Duley, F. L. (1926). *Soil Sci.* **21,** 401-9

Duley, F. L. and Ackerman, F. G. (1934). *J. Agric. Res.* **48,** 505-10

Duley, F. L. and Miller, M. F. (1923). *Miss. Agric. Expt. Sta. Res. Bull.* **63**

Eden, T. (1923). *Imp. Bur. Soil Sci. Tech. Comm. No.* **28**

Geikie, Archibald (1903). *Text-book of geology,* Vol. I

Gorrie, R. M. (1938). *Nature* **142,** 560-1

——————— (1939). *Imp. Coun. Agric. Res. Misc. Bull. No.* **28**

Holland, T. H. (1930). *Trop. Agric.* **75,** 248-50

Holland, T. H. and Joachim, A. W. R. (1933). *Trop. Agric.* **88,** 199-207

Jacks, G. V. and Whyte, R. O. (1938). *Imp. Bur. Soil Sci. Tech. Comm. No.* **36**

Lowdermilk, W. C. (1931). *Agric. Eng.* **12,** 107-12

Middleton, H. E. (1930). *U. S. D. Agric. Tech. Bull.* **178**

Miller, M. F. and Krusekopf, H. H. (1932). *Mo. Sta. Res. Bull.* **177**

Mosier, J. G. and Gustafson, A. F. (1918). *Illinois Agric. Expt. Sta. Bull.* **207**

Robinson, G. W. (1936). *Nature* **137,** 950

Royal Commission on Agriculture (1926). *Report*

Staples, R. R. (1936). *Rep. Dept. Vet. Sci. Tanganyika,* pp. 134-41. (Quoted by Jacks and Whyte, 1938)

Sahasrabudhe, D. L. (1929). *Agricultural geology of India*

Statistical Atlas of the Bombay Presidency, Third Edition (1925)

Thompson, W. R. (1935). *Univ. Pretoria Ser.* **1,** No. 29, 31 (Quoted by Jacks and Whyte, 1938)

APPENDIX I

(a) Rainfall received on rainy days classified according to intensity, during the experimental period of five years

Class	Rainfall in inches*	June	July	August	September	October	November	December	January	February	March	April	May
						(1934-35)							
1	0—¼ . .	0·10	0·17	0·17	0·11	0·10	0·18	...	0·19	...	...	0·23	0·11
		0·25	0·10	0·39	0·35	0·13	0·20	...	...	...	...	0·12	...
		0·11	0·17	0·31	*0·17*	...	...	...	...	...	...	...	...
			0·25	0·12	0·29								
			0·10	*0·36*	0·18								
			0·25	0·24	0·30								

APPENDIX I—*contd.*

Class	Rainfall in inches	June	July	August	September	October	November	December	January	February	March	April	May
(1934-35)—*contd.*													
			0·49		0·20								
			0·40		0·14								
			0·31		0·14								
			0·13										
2	½—1 . . .		0·93	0·95	0·75								
			0·50										
3	1—2 . . .			1·13	*1·22*		1·24						
				1·52									
4	Above 2 . .		*2·17*		*2·67*								
(1935-36)													
1	0—½ . . .	0·17	0·16	0·38	0·24	0·15	...	0·43	...	0·47	0·36	...	...
		0·20	0·12	0·14	0·41	0·43				0·26			
		0·16	0·13	*0·48*	0·29	0·23							
		0·34	0·12	0·47	0·25	0·42							
		0·13		0·23		0·13							
		0·20											
		0·26											
2	½—1 . . .	0·75											
		0·54	*0·78*	0·50	0·96	0·51						0·65	0·70
		0·69	0·65	*0·54*	0·99								
3	1—2 . . .			*1·57*									
				1·03									
				1·86									
4	Above 2 . .			*3·52*		*4·30*							
(1936-37)													
1	0—½ . . .	0·18	0·16	0·25	0·14	0·37				0·21	0·49	0·22	
			0·25	0·35	0·47						0·20	0·41	
			0·10	0·16	*0·42*								
			0·10		0·13								
2	½—1 . . .	0·84	*0·85*				*0·90*					0·56	
		0·70					0·69						
		0·56											
3	1—2 . . .				*1·73*							1·03	
4	Above 2 . .						*2·03*						

APPENDIX I—*contd.*

Class	Rainfall in inches	June	July	August	September	October	November	December	January	February	March	April	May
					(1937-38)								
1	0—½ . . .		0·16	0·15	0·30	0·39		*0·39*				0·11	0·31
			0·27	0·14	*0·38*			*0·34*					0·10
			0·47		0·32								
			0·33		*0·44*								
			0·42		0·28								
			0·17		0·12								
			0·14		0·26								
			0·24										
			0·21										
			0·22										
			0·14										
2	½—1 . . .	*0·98*	*0·63*	*0·54*		*0·67*					0·81		
		0·80		0·82		*0·62*							
3	1—2 . . .				*1·30*	*1·97*		*1·35*			*1·40*		
					1·15	*1·44*							
4	Above 2 . .				*2·13*								
					2·05								
					(1938-39)								
1	0—½ . . .	0·34	0·25	0·16	0·31	0·23						0·25	
		0·10	0·44	0·19	*0·26*							0·18	
		0·31	0·10	0·28									
		0·15	0·11	0·10									
		0·30	0·30	0·10									
		0·18	0·42	0·16									
		0·10	0·27	0·24									
		0·16	*0·34*	0·10									
			0·15	0·26									
			0·33										
			0·30										
			0·11										
			0·41										
			0·10										
2	½—1. . .	*0·94*	*0·96*	0·65	0·66	0·75							
		0·60		0·59	0·79								
					0·56								
3	1—2 . . .	*1·90*	*1·72*	1·60	*1·14*								
		1·50	*1·78*		*1·76*								
		1·78	1·13		*1·14*								
4	Above 2 . .		*2·32*		*4·06*								

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* The figures in *italics* indicate the rainfall that caused run-off of rain water and soil erosion.

APPENDIX I—*contd.*

(*b*) *Loss of rain water by run-off in inches and loss of soil by erosion in pounds per acre on each day of run-off during the experimental period of five years*

(1934-35)

Plot	Treatment	Dates	30-7-34	2-8-34	26-8-34	4-9-34	7-9-34	8-9-34
		Rainfall	2·17	1·52	0·36	1·22	2·67	0·17
1	Retention of vegetation	Run-off water	0·006	...	0·006	0·004	0·190	0·003
		Silt lost	1·15	...	7·69	0·70	48·50	0·83
2	Removal of vegetation	Run-off water	0·037	...	0·024	0·148	1·105	0·061
		Silt lost	13·69	...	107·72	239·55	1,648·03	45·29
3	Shallow cultivation	Run-off water	0·019	...	0·023	0·097	1·040	0·063
		Silt lost	3·54	...	47·37	59·62	975·86	56·48
4	Cultivation of *rabi jowar*	Run-off water	0·018	...	0·025	0·099	0·896	0·053
		Silt lost	6·39	...	12·60	160·81	1,979·25	67·90
5	'Scooping'	Run-off water	...	...	0·003	0·003	0·015	...
		Silt lost	...	...	8·38	1·73	6·17	...
6	Cultivation of a *kharif* crop of *bajri* and *tur*	Run-off water	0·037	0·032	0·011	0·053	0·505	0·043
		Silt lost	24·29	13·82	125·03	185·08	1,883·97	61·17
7	Thorough cultivation	Run-off water	0·123	0·021	0·023	0·145	1·067	0·042
		Silt lost	126·09	4·66	212·31	559·14	2,004·31	55·14
8	Thorough cultivation with double length	Run-off water	0·046	...	0·006	0·108	1·000	0·053
		Silt lost	6·05	...	44·45	78·74	1,130·66	31·78

APPENDIX I—*contd.*

(1935-36)

Plot	Treatment	Dates	26-6-35	5-7-35	24-8-35	25-8-35	27-8-35	28-8-35	29-8-35	30-8-35*	24-10-35*
		Rain-fall	0·69	0·78	3·52	0·48	1·57	1·03	0·54	1·86	4·30
1	Retention of vegetation	Run-off water	...	...	1·13	...	0·35	0·32	0·16	1·02	1·03
		Silt lost	...	...	419·0	...	145·4	201·4	92·0	7·5	453·9
2	Removal of vegetation	Run-off water	0·019	0·011	1·54	0·008	0·67	0·56	0·24	1·29	1·46
		Silt lost	9·3	5·80	3,697·0	1·4	898·0	1,585·0	1,461·0	31,940·0	16,365·0
3	Shallow cultivation	Run-off water	0·051	0·011	1·52	0·007	0·73	0·59	0·22	1·17	1·39
		Silt lost	40·4	3·9	5,217·0	2·6	971·6	1,635·5	878·0	85,570·0	40,000·0
4	Cultivation of *rabi jowar*	Run-off water	0·011	...	1·51	0·024	0·76	0·55	0·22	1·18	1·29
		Silt lost	2·7	...	11,140·0	18·7	4,325·0	6,800·0	2,544·0	137,800·0	97,160·0
5	'Scooping'	Run-off water	...	...	1·51	...	0·19	0·33	0·03	1·02	0·73
		Silt lost	...	...	5,966·0	...	464·7	1,165·0	336·5	43,120·0	36,870·0
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water	...	...	1·46	...	0·51	0·50	0·16	1·14	0·83
		Silt lost	...	...	38,635·0	...	1,726·6	14,890·0	846·1	36,100·0	6,461·0
7	Thorough cultivation	Run-off water	...	...	1·37	0·006	0·63	0·38	0·22	1·25	1·15
		Silt lost	...	...	21,460·0	3·8	4,689·0	6,586·0	1,735·0	53,510·0	124,400·0
8	Thorough cultivation with double length	Run-off water	...	...	1·51	...	0·51	0·29	0·20	1·24	1·54
		Silt lost	...	...	11,570·0	...	626·4	2,264·0	729·3	48,770·0	39,680·0

* Shows rainfall of great intensity mentioned in Table XVII

APPENDIX I—*contd.*

(1936-37)

Plot	Treatment	Date	23-7-36	26-9-36	28-9-36	13-11-36*	14-11-36*
		Rainfall	0·85	1·73	0·42	2·03	0·90
1	Retention of vegetation	Run-off water	...	0·05	...	0·02	...
		Silt lost	...	92·6	...	69·49	...
2	Removal of vegetation	Run-off water	0·09	0·48	0·04	0·27	0·18
		Silt lost	101·6	775·3	65·0	592·6	911·0
3	Shallow cultivation	Run-off water	0·04	0·70	0·06	1·02	0·40
		Silt lost	57·9	909·5	84·5	2,381·0	3,775·0
4	Cultivation of *rabi jowar*	Run-off water	...	0·69	0·01	0·82	0·37
		Silt lost	...	1,051·0	22·3	3,514·0	5,174·0
5	'Scooping'	Run-off water	...	0·09	...	0·10	0·005
		Silt lost	...	433·0	...	291·6	64·59
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water	...	0·48	...	0·76	0·34
		Silt lost	...	596·9	...	11,690·0	6,144·0
7	Thorough cultivation	Run-off water	...	0·68	0·03	0·83	0·39
		Silt lost	...	969·8	47·2	37,190·0	1,301·9
8	Thorough cultivation with double length	Run-off water	...	0·78	0·02	0· 0	0·49
		Silt lost	...	688·0	25·7	1,151 0	673·3

* Shows rainfall of great intensity mentioned in Table XVII

APPEN

(1937-

Plot	Treatment	Date . .	17-6-37	19-6-37	6-7-37	10-7-37 11-7-37	5-8-37	2-9-37	3-9-37
		Rainfall .	0·98	0·80	0·47	0·96	0·54	1·30	0·88
1	Retention of vegetation	Run-off water	...	...	...	...	...	...	...
		Silt lost .	...	...	...	...	...	...	...
2	**Removal of vegetation**	**Run-off water**	...	0·22	0·07	0·13	0·03	0·28	...
		Silt lost .	...	323·4	278·3	198·1	64·8	203·0	...
3	**Shallow cultivation**	**Run-off water**	0·26	0·43	0·08	0·15	0·08	0·61	Trace
		Silt lost .	371·5	902·4	362·1	267·7	121·5	388·8	14·56
4	**Cultivation of *rabi jowar***	**Run-off water**	0·21	0·42	Trace	0·08	...	0·38	...
		Silt lost .	373·0	1,614·0	87·32	124·6	...	280·0	...
5	**(Scooping)** .	**Run-off water**	0·19	0·37	...	...	...	0·24	...
		Silt lost .	358·8	1,788·0	...	...	...	232·7	...
6	**Cultivation of *khari*. crop of *bajri* and *tur***	**Run-off water**	0·18	0·40	Trace	0·07	...	0·45	...
		Silt lost .	287·1	1,806·0	85·6	146·5	...	220·2	...
7	**Thorough cultivation**	**Run-off water**	0·03	0·39	Trace	0·08	...	0·41	...
		Silt lost .	121·1	1,381·0	79·40	150·3	...	407·2	...
8	**Thorough cultivation with double length**	**Run-off water**	0·05	0·36	...	0·06	...	0·50	...
		Silt lost .	103·7	438·8	...	91·4	...	336·9	...

(1938

Plot	Treatment	Date .	7-6-38 8-6-38	19-6-38	20-6-38 21-6-38	22-6-38
		Rain-fall	2·0	1·50	2·72	0·60
1	Retention of vegetation . .	Run-off water . .	...	...	0·15	...
		Silt lost . . .	...	...	66·9	...
2	Removal of vegetation . .	Run-off water . .	0·38	0·56	1·59	0·15
		Silt lost . . .	229·5	1,154·0	1,986·0	88·0
3	Shallow cultivation . . .	Run-off water . .	0·28	0·57	1·55	0·16
		Silt lost . . .	173·2	865·4	2,187·0	83·8
4	Cultivation of *rabi jowar* . .	Run-off water . .	...	0·35	1·27	0·12
		Silt lost . . .	...	441·0	2,010·0	78·4
5	'Scooping'	Run-off water . .	...	...	Trace	...
		Silt lost . . .	...	...	106·2	...
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water . .	...	0·34	1·09	0·08
		Silt lost . . .	...	533·8	3,960·0	55·38
7	Thorough cultivation . .	Run-off water . .	...	0·41	1·28	0·011
		Silt lost . . .	...	448·8	3,359·0	67·0
8	Thorough cultivation with double length	Run-off water . .	...	0·04	1·19	0·08
		Silt lost . . .	...	90·6	660·1	46·6

DIX I—*contd.*

38)

21-9-37	22-9-37	*24-9-37	*25-9-37	2-10-37	3-10-37* 4-10-37	5-10-37	13-12-37	14-12-37	24-12-37	26-3-38
1·15	0·44	2·13	2·05	0·67	2·59	1·44	0·39	0·34	1·35	1·40
...	...	0·24	0·31	...	0·10	...	...	...	Trace	...
...	...	145·1	185·6	...	73·63	...	...	...	100·9	...
0·29	0·06	1·20	1·42	0·30	1·26	0·61	...	...	Trace	0·49
394·1	95·8	58,650·0	75,010·0	78·2	55,650·0	4,109·0	...	...	942·3	712·2
0·48	0·08	1·39	1·37	0·22	1·08	0·48	0·01	0·01	1·05	0·58
589·4	107·4	79,930·0	89,300·0	1,294·0	72,810·0	3,075·0	31·02	47·2	4,435·0	739·2
0·46	Trace	1·38	1·39	0·16	1·07	0·48	...	...	1·07	0·37
349·4	11·82	16,500·0	115,000·0	805·0	44,230·0	3,256·0	...	...	15,410·0	838·1
...	...	0·55	0·96	0·15	0·87	0·40	...	...	0·57	0·02
...	...	35,130·0	40,100·0	799·1	22,720·0	8,782·0	...	...	2,885·0	168·7
0·18	...	1·42	1·28	0·19	1·08	0·62	...	...	0·78	0·34
215·3	...	117,300·0	93,670·0	1,172·0	34,040·0	6,816·0	...	...	5,331·0	854·3
0·40	0·04	1·27	1·29	0·27	1·23	0·46	...	...	0·92	0·35
549·3	73·60	113,200·0	94,450·0	3,390·0	35,850·0	9,397·0	...	...	3,533·0	582·9
0·42	0·03	1·40	1·22	0·26	1·35	0·50	...	...	1·13	0·46
417·8	40·30	76,470·0	134,000·0	3,125·0	55,440·0	10,810·0	...	...	4,255·0	501·4

39)

*3-7-38	6-7-38	8-7-38	13-7-38	16-7-38	3-9-38	10-9-38	21-9-38	*24-9-38 25-9-38
2·32	1·72	1·78	0·34	0·96	1·14	1·76	1·14	4·32
Trace	...	...	...	...	...	...	...	0·49
47·4	...	...	...	...	...	...	...	254·6
1·59	0·48	0·36	0·02	0·24	0·48	0·96	0·49	2·74
12,310·0	799·7	626·2	42·0	360·2	792·3	1,810·0	2,019·0	23,560·0
1·40	0·47	0·31	0·01	0·20	0·43	0·89	0·49	2·75
12,640·0	11,49·0	226·8	27·8	269·3	313·4	1,521·0	3,796·0	16,990·0
1·15	0·03	Trace	...	0·06	0·31	0·60	0·42	2·61
13,650·0	44·8	10·7	...	39·4	195·2	729·5	2,446·0	54,920·0
0·02	...	...	...	...	...	0·17	0·04	1·78
130·4	...	...	...	...	...	176·7	230·4	29,730·0
0·62	0·10	0·07	...	0·08	0·11	0·13	0·04	1·75
1,916·0	120·4	91·0	...	73·3	98·9	116·1	229·2	24,340·0
0·63	0·20	0·03	...	0·07	0·31	0·64	0·38	2·35
21,330·0	189·2	29·0	...	74·8	175·1	416·5	1,090·0	40,480·0
1·16	0·13	Trace	...	0·05	0·38	0·67	0·41	2·19
2,034·0	86·7	23·3	...	9·5	216·7	523·4	753·6	58,060·0

* Shows rainfall of great intensity mentioned in Table XVII

APPENDIX I—*concld.*

(*c*) *Total soluble salts in run-off water*

(Expressed in pounds per acre)

Plot No. and treatment	1934-35	1935-36	1936-37	1937-38	1938-39	Total during 5 years 1934-35 to 1938-39	Average per annum
1. **Retention of vegetation** .	11·18	75·09	5·57	16·45	23·32	131·61	26·32
2. **Removal of vegetation** .	53·31	101·70	24·39	138·87	255·70	573·97	114·79
3. **Shallow cultivation** . .	43·43	124·51	36·90	174·48	297·70	677·02	135·40
4. **Cultivation of *rabi jowar*** .	48·31	104·41	26·06	148·06	234·02	560·86	112·17
5. **'Scooping'**	6·06	81·60	2·28	101·51	71·08	268·53	53·70
6. **Cultivation of *kharif bajri* and *tur***	36·12	83·27	28·29	143·66	155·59	446·23	89·38
7. **Thorough cultivation** . .	37·81	93·07	30·84	143·74	175·17	490·63	98·12
8. **Thorough cultivation with double length**	41·68	88·48	33·22	130·55	171·54	465·27	93·05

(*d*) *Total soluble lime* (CaO) *in run-off waters*

(Expressed in pounds per acre)

Plot No. and treatment	1934-35	1935-36	1936-37	1937-38	1938-39	Total during 5 years 1934-35 to 1938-39	Average per annum
1. **Retention of vegetation** .	3·18	31·83	1·31	6·58	6·95	49·85	9·97
2. **Removal of vegetation** .	15·06	42·74	6·27	48·83	98·86	211·76	42·35
3. **Shallow cultivation** . .	15·75	51·09	10·57	71·43	101·87	250·71	50·14
4. **Cultivation of *rabi jowar*** .	18·62	44·42	9·22	62·44	91·18	225·88	45·17
5. **'Scooping'**	1·43	24·62	2·42	37·67	30·46	96·60	19·32
6. **Cultivation of *kharif bajri* and *tur***	8·43	36·36	9·76	64·14	64·94	182·63	36·52
7. **Thorough cultivation** . .	7·87	37·09	9·10	57·57	74·55	186·27	37·25
8. **Thorough cultivation with double length**	10·31	30·24	9·45	57·36	72·63	179·99	35·99

APPENDIX II

STANDARD ERROR OF THE TWO RUN-OFF PLOTS RECEIVING SIMILAR TREATMENTS

An attempt is made here to answer any possible objection regarding the single-plot lay-out mentioned earlier. Fortunately we have some data to throw light on the possible variation between two similar plots. Plots 4 and 7 were practically the same. Plot 4 had a *rabi* crop of *jowar* from October onwards, but most of the run-offs took place before the sowing of the crop, and therefore both the plots can be considered as comparable. The data of quantities of water lost by run-off as calculated in inches from these plots during the five years are as follows.

Inches of rainfall lost by run-off

	1934-35	1935-36	1936-37	1937-38	1938-39	Total for five years
Plot 4 . .	1·09	5·55	1·89	7·47	6·92	22·92
Plot 7 . .	1·42	5·02	1·93	7·14	6·41	21·92

The results in all the years show such a great agreement between the two plots that no objection may be raised regarding the single-plot lay-out. Further, in order to find out the probable variation in the two plots receiving exactly the same treatment, the results of run-off during five years are again compared, after omitting the run-offs obtained after sowing of the *rabi jowar* in October. The following table shows the actual figures thus obtained for the two plots for five years.

Years	Plot 4	Plot 7	Total
1934-35	1·09	1·42	2·51
1935-36	4·26	3·87	8·13
1936-37	0·70	0·71	1·41
1937-38	6·14	5·87	12·01
1938-39	6·92	6·41	13·33
Total .	20·54	19·85	40·39

Analysis of variance

Due to	Degrees of freedom	Sum of squares	Mean square	Z theo.
Treatments . . .	1	0·07	0·07	Not significant for 5 per cent
Season	4	58·36	14·59	Significant for 1 per cent
Error	4	0·22	0·055	
Total .	9	58·65	..	

The analysis of variance clearly indicates that the variation between plots is very small and is not statistically significant.

A STATISTICAL STUDY OF THE RELATION BETWEEN QUALITY AND RETURN PER ACRE IN COTTON *

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WIDESPREAD attempts are being made at present to introduce long or medium-staple varieties of cotton in the short-staple tracts of India. The incentive behind this policy is primarily the demand of mill interests for a better quality product and also the partial dwindling of the foreign market for the short-staple Indian cotton. There has, therefore, been an increasing tendency to emphasize this objective in cotton breeding. In pursuing this objective, however, the vital importance of agricultural considerations such as yield cannot be ignored. In the long run agricultural factors must have full consideration, since the establishment of a new strain, however superior in quality, depends on its capacity to increase the return per acre to the cultivator, and this point is recognized by the Indian Central Cotton Committee in its policy of financing breeding schemes. Return per acre is an integration of two components, the premium obtainable for quality and the yield of lint per acre. Both the factors must, therefore, be considered together.

Opportunity was taken to study the problem in Malwa (Central India), where side by side with the indigenous cotton (*G. arboreum* var. *neglectum* forma *bengalensis*) there exists the cultivation of Cambodia (*G. hirsutum*), a superior Upland type, introduced over 20 years back. Spinners are, therefore, familiar with it, and difficulties which sometimes arise in the valuation of new and unfamiliar cottons are absent. Mills at Indore purchase it freely at a premium over the indigenous or *desi* cotton and are insistent in their demand that its cultivation shall be extended. The Institute of Plant Industry has recently commenced the distribution of a superior *desi* strain (Malvi 9) which has become popular with the cultivators on account of its higher yield and ginning, and Indian States in Malwa are trying to multiply it as rapidly as possible. Replicated yield trials of these three types, the Upland, the Malvi local and Malvi 9, under different conditions of cultivation were specially carried out at several centres in the years 1934 and 1935, and additional comparisons in other seasons are also available. Data on spinning quality and commercial valuations of different *desi* and Upland samples grown in Malwa are available for eight years (1931-38). The material is, therefore, eminently suitable for a study of the relation between price and spinning quality and its bearing on return per acre.

The commercial valuation of a cotton represents the price that the trade is pepared to pay and this price depends not only on the quality of the cotton but also on extraneous factors related to market conditions, such as the demand and supply of various types. In other words, the relation between price and quality is subject to the influence of these factors and may change in different seasons. The present data, which cover a sufficiently long period, have been examined in order to discover whether the relation between price and quality has in fact altered within this period, by the differential operation of these factors, as far as Indian cottons ranging in quality from 10 to 30 counts are concerned.

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*An abridged form of this paper was presented and discussed at the Second Conference of Scientific Research Workers on Cotton in India, Bombay, January 1941.

QUALITY AND PRICE

One hundred and sixty-three samples of selected and unselected *desi* and Upland cotton and of local mixtures grown at several centres in Malwa from 1931 to 1938 have been tested at the Indian Central Cotton Committee's Technological Laboratory at Bombay. Commercial valuations and figures for spinning quality in terms of 'highest standard warp counts' [Nazir Ahmad, 1932] as reported by the Director of the Technological Laboratory are given in Tables I-IV. Commercial values are given in rupees per candy (784 lb.) 'on' or 'off' the Broach basic price on the day of valuation. This basic price is attached to all grader's reports issued by the Technological Laboratory. To allow for the effect of fluctuations in the Broach basis, the differences have been re-calculated as percentages of the Broach basis and entered in the last column of each table.

Regressions of percentage difference in price on spinning value were calculated for each season separately and also an average regression for the whole period by pooling together the necessary sums of squares and products within each season. The regression coefficients and their standard errors are given below :—

Season	1931	1932	1933	1934	1935	1936	1937	1938	Average
Regression coefficient .	0·81	0·53	1·90	0·10	0·64	0·65	0·74	0·58	0·66
Standard error . . .	0·486	0·296	0·492	0·490	0·209	0·089	0·326	0·187	0·076
P .	>0·05	>0·05	<0·01	Large	0·01	<0·01	<0·05	<0·01	<0·01

The regression value in the last column means that an average premium of 0·66 per cent of the Broach basis was obtained during the period 1931-38 for each increase of one count in spinning value. The individual values have ranged from 1·90 in 1933 to 0·10 in 1934, and the question whether this variation is significant, that is, whether extraneous factors have altered the premium significantly in the different seasons, can be answered by testing the heterogeneity of the regression coefficients. The regression sums of squares ($bSxy$) each with one degree of freedom and the residual sums of squares of percentage price difference ($Res.\ Sy^2$) with their respective degrees of freedom, which are required for making this test, are as follows :—

Season	*bSxy*	*Res. Sy²*	Degrees of freedom
1931	93·27	237·10	7
1932	75·73	398·63	17
1933	268·14	198·09	11
1934	0·65	81·80	5
1935	168·80	178·62	10
1936	1,244·95	842·93	36
1937	288·89	1,725·90	31
1938	249·04	769·57	30
Total	2,389·47	4,432·64	147

The total of the second column represents the regression sum of squares with eight degrees of freedom, and this can be split up into two parts, one corresponding to the average regression with one degree of freedom which is 2,237·91, and the other to differences between individual regressions with seven degrees of freedom. The significance of each of these components can be tested against the total of the residual sums of squares of percentage price differences, which is the appropriate error for this purpose. The analysis of variance takes the following form :—

Analysis of variance for testing homogeneity of regression

Due to	Degrees of freedom	Sum of squares	Mean square
Average regression	1	2,237·91	2,237·91
Differences between regression	7	151·56	21·65
Error	147	4,432·64	30·15

The mean squares for the last two items are nearly the same, and there is thus no evidence whatsoever that the regression of price on spinning quality differed significantly from season to season. It is clear that whatever be the extraneous factors affecting the premium paid for quality, they have not altered the rate of this premium in the different seasons and in judging the relative price obtainable for varieties differing in quality we need only consider the premium determined by the average regression. The regression equation is, $Y=1\cdot1936+0\cdot6593\,(x-20\cdot29)$, where x is the spinning value of a sample and Y its predicted valuation in terms of percentage difference from the Broach basis.

The absence of any evidence of heterogeneity among the regression coefficients in spite of the strikingly different values for the years 1933 and 1934 might be due to these coefficients being based on only a small number of degrees of freedom and having a higher error than the remaining coefficients. It will be noted that the number of samples during the period 1931-35 was smaller than in the subsequent three years ; but average regression coefficients calculated for the two periods separately were 0·6945 and 0·6512 respectively and a test for heterogeneity of regression within each period also showed that such heterogeneity did not exist. The analysis thus confirmed the conclusions described above.

Spinning values of 20 samples of Malvi 9, 27 of Cambodia and nine of local cotton are included in Tables I-III. Mean values and standard errors calculated from these data are given below :—

Variety	Mean spinning value (highest standard warp count)	Standard error of the mean	Standard error per cent of the mean
Malvi 9	18·3	0·83	4·5
Cambodia	27·3	0·70	2·5
Local cotton	12·1	0·37	3·0

The standard errors are low and indicate that the variation in the spinning value of a variety due to seasonal and locational differences within a tract is comparatively small. By substituting the mean spinning values of the three varieties in the regression equation, the average premium obtainable for each variety during the eight-year period under discussion was estimated. Cambodia was found to secure a price 10·46 per cent higher than the local cotton and 5·94 per cent higher than Malvi 9. This premium, however, corresponds to a 125 and 50 per cent improvement in spinning quality respectively.

That the relationship between price and quality calculated from the present data restricted to Central Indian cottons is probably a general one over the usual range of Indian cottons (10-40 counts) is confirmed by an examination of data from other sources. Koshal [1936] has given spinning values and commercial valuations for 65 samples of 12 varieties of Indian cotton spread over the period from 1926 to 1934. To these may also be added nine more values belonging to the varieties Cawnpore K22, Verum 262 and

Umri-Bani within the same period [Kapadia, 1936], which are not included in Koshal's data but are relevant for the purpose of the present analysis. The regression equations for price and spinning value calculated from these samples are given below :—

(i) $Y=186\cdot0+0\cdot8259\ (x-28\cdot75)$, from 65 samples

(ii) $Y=183\cdot7+1\cdot0956\ (x-27\cdot50)$, from 74 samples

where x is the spinning value of a given sample, and Y its predicted commercial value with the Broach basis at Rs. 155 per candy.

Substituting in these equations the mean spinning values of the varieties under discussion, we find from equation (i) that Cambodia obtains a price 7·3 per cent higher than the local cotton and 4·2 per cent higher than Malvi 9, the corresponding figures from equation (ii) being 10·0 and 5·7 per cent respectively. It is interesting to note that the premium for Cambodia calculated from the second equation is almost identical with that obtained from the Central Indian data. The confirmation is striking in view of the fact that Koshal's data consisted of an entirely different set of varieties covering an earlier period of five years, and in estimating the regression seasonal differences were ignored. It may be concluded that over the range of quality of Indian cottons there is a uniform relationship between price and quality, and it was not materially affected by seasonal fluctuations in market conditions and other extraneous factors during the period from 1926 to 1938. We may, therefore, confidently use the regression values as a basis for studying the profitableness or otherwise of superior varieties to the cultivator.

YIELD AND RETURN PER ACRE

It will be seen from the previous section that the margin of profit obtainable by growing superior varieties is narrow. If superior varieties tend to give any appreciably lower yield than the locally grown cotton or to require a more costly cultivation, their advantage will rapidly disappear. On the basis of the premium available for quality, Cambodia would provide equal returns per acre with Malvi 9 and local cotton with a 9·47 and 5·61 per cent lower yield of lint respectively. If the yield of lint from Cambodia fell below this level, its cultivation would become less profitable than that of the other two varieties.

Nine replicated trials were made to test the relative yields of Cambodia, Malvi 9 and local cotton on different types of land in Malwa. In 1934-35 four trials were carried out on ordinary unirrigated (*barani*) land, and one trial on rich manured and irrigated (*adhan*) land. In 1935-36 four more trials were carried out on *adhan* land. Strictly comparable yield figures for these varieties are available from another group of four trials made on ordinary land at Indore from 1935-36 to 1939-40. All these trials consisted of six to eight randomized blocks and the plot size was 1/100 acre. Yields of *kapas* (seed-cotton), ginning percentage and calculated yields of lint per acre from these 13 trials are given in Tables V-VII.

Percentage differences in the yield of lint between Cambodia on one hand and Malvi 9 and local cotton on the other calculated from these tables are given below :—

Experiments on *barani* land				Experiments on *adhan* land			
Per cent difference from Malvi 9		Per cent difference from Local		Per cent difference from Malvi 9		Per cent difference from Local	
1934	−52·1	1934	−42·5	1934	−49·5	1934	−39·2
	−50·9		−45·6				
	−34·2		−28·6	1935	−31·6	1935	−21·9
	(−30·7)		(−70·7)		−17·2		−9·5
1935	−29·7				−9·7		+2·9
		1938	+9·2		−4·7		+110·0†
			−18·4				
1938	+48·8*	1939	−32·2				
	−13·8						
1939	−39·0						

* Stand of Malvi 9 was very poor.

† Local seed was badly ginned and did not germinate well.

Figures in brackets are based on yields of seed-cotton, because ginning percentages were not estimated in this trial. Differences in the yield of lint would, however, be of the same order, as these varieties do not differ appreciably in their ginning percentages.

Referring to the percentage yield disadvantages at which Cambodia gives returns equal to those of the other two varieties, it is obvious that the yield of Cambodia is so much below this limit that its cultivation would be distinctly less profitable than that of the two *desi* varieties on *barani* land. Even on *adhan* land, for which Cambodia was considered specially suitable, the position is not more hopeful. Unless a strain capable of giving a considerably higher yield is evolved, Cambodia cannot be recommended to the cultivators in Malwa.

DISCUSSION

The conclusion that the superior quality Cambodia is less profitable to the grower in Malwa than the inferior indigenous types is based on the price-quality relationship obtaining during the eight-year period 1931-38, to which a further five years from 1926 may be added in view of the confirmatory evidence from Koshal's data. It is difficult to predict the future trend of prices and while the present relationship between price and quality may change, it is inconceivable that the change would be so drastic that Cambodia would give at least the same return as the two indigenous types if not more. It is obvious that only very small sacrifices in yield can be permitted if the return per acre from a variety of superior quality is to equal that of the variety it is designed to replace.

The present conclusions with regard to Central Indian cottons are of a much wider application. Instances can be quoted from other parts of the world where a similar situation exists between superior quality varieties and inferior but better yielding or better ginning varieties. I am indebted to Mr J. B. Hutchinson for the following data concerning the Bourbon and Barbadense constituents of the Marie Galante cotton of Carriacou, West Indies. At present, the two are grown mixed in all proportions in the fields, but spinning tests have shown that both are good marketable cottons of their own particular types if sold pure. Bourbon spins very much better than the Barbadense, the former being estimated to spin 35 counts as against only 14's of the latter. (These are Shirley Institute Highest Standard Counts. On the Bombay Technological Laboratory standards, the highest standard warp counts would be higher). The commercial valuation of Bourbon is 5·69*d* per pound of lint or 100 points ' on ' Middling American and of the Barbadense, 4·94*d* or 25 points ' on '. Proper yield trials for these varieties have not been made, but their ginning percentages are 22·2 for Bourbon and 27·9 for Barbadense, and if the lint value of 100 pounds of seed-cotton is worked out, it appears that Barbadense is worth 138*d* per 100 pounds of seed-cotton as against only 126*d* for the Bourbon. It is clear that even if these two varieties do not differ in the yield of seed-cotton, the inferior Barbadense is more profitable to the cultivator than Bourbon. The premium obtainable for the superior quality of Bourbon is too small to offset the disadvantage of a lower ginning percentage.

Before closing this discussion reference should be made to an investigation on this problem by Kapadia [1936] and its criticism by Mahalanobis [1936] and Koshal [1936]. From an examination of technological reports of Indian cottons, Kapadia concluded that improvement in quality progressively reduces the money return per acre. He arrived at this conclusion by comparing the high yielding but poor quality cottons of Northern India and Gujerat with the low yielding but better quality cottons of the South and omitting from consideration superior varieties like the Punjab and Cawnpore Americans from high-yielding tracts. Mahalanobis after correcting this omission came to the slightly different conclusion that when spinning value goes beyond 38, the return per acre increases. Koshal analysed data for 65 samples covering 12 varieties, for which individual yield figures were readily available. He found that there is no relationship between spinning value and the return per acre. It should be noted, however, that Koshal could not include the comparatively inferior but high-yielding varieties like Cawnpore K22 and Verum 262 in his analysis, presumably for want of proper yield data, but even so, the absence of any significant correlation between quality and return per acre in his material is chiefly due to a significant negative correlation (—0·26) between spinning value and yield of lint per acre being counterbalanced by a significant positive correlation (+0·29) between spinning value and commercial valuation.

From the agricultural point of view, the relative returns per acre of a series of varieties of different spinning qualities are of no value, unless they have been obtained from crops grown on the same land. The comparison made by Kapadia, Mahalanobis and Koshal are not relevant to the practical problem, in that they all deal with varieties grown under entirely different conditions in tracts of widely different yield potentialities. In the present investigation, exactly opposite—and equally irrelevant—results would be obtained by comparing Cambodia cotton grown on rich *adhan* lands with *desi* cotton grown on poor *barani* lands.

The conclusions to be drawn from the investigation of the quality-price relationship are important and of general application to cotton breeding. Improvement of the quality of Indian cotton is a pressing need ; but the regression coefficients given above show conclusively that in the present state of the world market, the increase in return with increasing quality is quite disproportionately small. Yield thus becomes by far the most important factor in determining the return per acre from a cotton variety. This does not mean that the breeder should disregard quality and breed entirely for yield but it does mean that while breeding for quality he must pay adequate attention to yield also, because a premium for quality adequate to compensate for more than quite a small loss in yield is not ordinarily realized.

SUMMARY

The relationship between quality and price has been studied in data of spinning tests and commercial valuations of samples grown in Malwa over a period of eight years from 1931 to 1938. It has been shown that the premium for quality is small and this result has been confirmed by an examination of other Indian cottons. Yield, therefore, should receive primary consideration when introducing superior varieties.

Cambodia cotton has been compared with local *desi* cotton and Malvi 9 for yield and money return per acre. It has been shown that Cambodia, in spite of its superior quality, cannot be recommended to the cultivators on account of its lower yield.

The effect of the relationship between quality and price on cotton breeding policy has been discussed and it has been pointed out that a premium for quality adequate to compensate for more than quite a small loss in yield is not ordinarily realized. Therefore, yield and ginning percentage must be taken into account in breeding for superior quality.

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REFERENCES

Kapadia, D. F. (1936). *Sankhya* **2**, 125

Koshal, R. S. (1936). *Sankhya* **2**, 443

Mahalanobis, P. C. (1936). *Sankhya* **2**, 135

Nazir Ahmad (1932). *Ind. Cent. Cot. Com. Tech. Bull. Series A, No.* **21**

TABLE I

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

((Malvi 9)

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1931	Good land, I. P. I.*	13½	166	0	0
1932	Med. land, I. P. I.	14	208	—3	—1·44
1932	Poor land, I. P. I.	15½	208	0	0
1932	Narsingarh	17	201	+14	+6·96
1933	Med. and poor land, I. P. I.	17	210	—5	—2·38
1933	Holkar State, Narsingarh, Dhar	15	210	—10	—4·76
1933	Med. land, I. P. I.	17	210	+15	+7·14
1933	Good land, I. P. I.	18	210	+20	+9·52
1934	Piplia	19	226	—5	—2·21
1934	I. P. I. and Ujjain	21	226	—25	—11·06
1935	Med. land, I. P. I.	16	212	+10	+4·72
1935	*Adhan* land, Kharua	15	212	+5	+2·36
1936	Med. land, I. P. I.	15	189	—3	—1·59
1936	*Adhan* land, Kharua	24	189	+5	+2·64
1937	Good land, I. P. I.	19	157	+5	+3·18
1937	Med. land, I. P. I.	23	156½	0	0
1937	*Adhan* land, Kharua	28	156½	+15	+9·58
1938	Good land, I. P. I.	18	270	+10	+3·70
1938	Med. land, I. P. I.	21	278	—18	—6·47
1938	*Adhan* land, Kharua	20	278	0	0

*** Institute of Plant Industry, Indore**

TABLE II

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

(Cambodia, Upland)

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1932	Med. land, Dhar	24	204	+10	+4·90
1932	*Adhan* land, Ratlam	22	204	+10	+4·90
1935	Musakheri	14½	212	—3	—1·41
1935	*Adhan* land, Kharua	32	212	+20	+9·43
1936	*Adhan* land, Kharua	26	186	+25	+13·44
1936	*Adhan* land, Kharua	28	186	+10	+5·37
1936	*Adhan* land, Badnawar	29	189	+45	+23·80
1937	I. P. I.	24½	157	+10	+6·37
1937	I. P. I.	26	157	+5	+3·18
1937	I. P. I.	25	157	+10	+6·37
1937	Medium land, Kharua	26	156½	—5	—3·19
1937	Medium land, Kharua	25	156½	—15	—9·58
1937	Medium land, Kharua	30	156½	+25	+15·97
1937	Medium land, Kharua	27	156½	—10	—6·39
1937	*Adhan* land, Kharua	28	156½	—5	—3·19
1937	*Adhan* land, Kharua	29	156½	+20	+12·78
1937	*Adhan* land, Kharua	31	156½	+15	+9·58
1937	*Adhan* land, Kharua	32	156½	+15	+9·58
1937	*Adhan* land, Badnawar	26	157	+5	+3·18
1938	Good land, I. P. I.	30	270	+7	+2·59
1938	Good land, I. P. I.	27	270	+1	+0·37
1938	Good land, I. P. I.	29	270	+7	+2·59

TABLE II—*contd.*

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1938	Good land, I. P. I. . .	30	270	—2	—0·74
1938	*Adhan* land, Kharua . .	31	270	+20	+7·41
1938	*Adhan* land, Kharua . .	28	270	+17	+6·30
1938	*Adhan* land, Kharua . .	30	270	+20	+7·41
1938	*Adhan* land, Kharua . .	28	270	+16	+5·92

TABLE III

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

(Local cotton)

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1931	Good land, I. P. I. . .	12	166	0	0
1932	Med. land, I. P. I. . .	10½	208	—5	—2·40
1932	Poor land, I. P. I. . .	13	208	—25	—12·02
1932	Narsingarh . . .	13	201	+8	+3·98
1933	Med. and poor land, I. P. I..	11	210	—10	—4·76
1933	Holkar State . . . Narsingarh . . . Dhar	12	210	—20	—9·52
1935	Musakheri . . .	11½	212	—15	—7·07
1935	*Adhan* land, Kharua . .	14	212	+8	+3·77
1836	Med. land, Dhar . .	11½	183	—5	—2·73

TABLE IV

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

(Other strains)

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1931					
Malvi 1 .	Good land, I. P. I. .	10	166	+15	+9·04
Malvi 3 .	Good land, I. P. I. .	13	166	+25	+15·06
Malvi 5 .	Good land, I. P. I. .	11	166	+20	+12·05
Malvi 8 .	Good land, I. P. I. .	7	166	+10	+6·02
Malvi mixed selections	Good land, I. P. I. .	14	155	+15	+9·68
Roseum 15 .	Good land, I. P. I. .	7	155	0	0
Indore 1 (Upland)	Good land, I. P. I. .	21	155	+25	+16·13
1932					
Malvi 1 .	Med. land, I. P. I. .	12½	208	—5	—2·40
Malvi 5 .	Med. land, I. P. I. .	12½	208	—3	—1·44
Malvi mixed selections	Med. land, I. P. I. .	13	208	—5	—2·40
Indore 25 (Upland)	Med. land, I. P. I. .	12½	204	—15	—7·35
Indore 1 (Upland)	Med. land, I. P. I. .	14	204	—10	—4·90
Malvi 1 .	Poor land, I. P. I. .	12½	208	0	0
Malvi 5 .	Poor land, I. P. I. .	13	208	—5	—2·40
Malvi 1 .	Narsingarh . .	15	201	+15	+7·46
Malvi 5 .	Narsingarh . .	16	201	+12	+5·97
Indore 25 (Upland)	Dhar . . .	21	204	—10	—4·90
Indore 1 (Upland)	Ratlam . . .	21	204	0	0

TABLE IV—*contd.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1933					
Malvi 1 .	Med. and poor land, I. P. I.	10	210	—10	—4·76
Malvi 5 .	Med. and poor land, I. P. I.	14	210	—5	—2·38
Malvi 1 .	Holkar State, Narsingarh, Dhar	13	210	—10	—4·76
Malvil 5 .	Holker State, Narsingarh, Dhar	14	210	—5	—2·38
Malvi 1 .	Good land, I. P. I. .	14	210	+5	+2·38
Malvi 1 . .	Asrawad . . .	13	210	—20	—9·52
Malvi 1 . .	Rau . . .	11	210	—25	—11·90
1934					
Dhar mass Malvi	Dhar . . .	17	226	—20	—8·85
Malvi 1 .	Badnawar . .	12	226	—25	—11·06
Malvi 1 . .	I. P. I. and Ujjain .	16	226	—30	—13·27
Malvi G-51 .	I. P. I. and Ujjain .	12	226	—15	—6·64
Malvi G-16 .	I. P. I. and Ujjain .	15	226	—15	—6·64
1935					
Malvi 9-13 .	Med. land, I. P. I. .	20	212	+15	+7·07
Malvi 9-15 .	Med. land, I. P. I. .	15	212	+5	+2·36
Malvi 9-17 .	Med. land, I. P. I. .	22	212	+20	+9·43
Malvi 9-19 .	Med. land, I. P. I. .	13	212	+18	+8·49
Malvi 9-20 .	Med. land, I. P. I. .	21	212	+25	+11·79
Malvi unselected	Poor land, Musakheri	9	212	—5	—2·36

TABLE IV—*contd.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1936					
Malvi 43-1 .	Dhar . . .	9	183	—5	—2·73
Malvi 43-7 .	Dhar . . .	10	183	—12	—6·55
Malvi 43-3 .	Dhar . . .	11	183	+5	+2·73
Malvi 43-2 .	Dhar . . .	13	183	—7	—3·82
Malvi 43-6 .	Dhar . . .	13½	183	—15	—8·19
Malvi 43-5 .	Dhar . . .	13½	183	—5	—2·73
Malvi 43-4 .	Dhar . . .	14	183	0	0
Roseum M .	Dhamnod . .	10½	193	0	0
Nimari local .	Dhamnod . .	11	193	0	0
Nimari M 1 .	Dhamnod . .	12	193	+10	+5·18
Banilla . .	Dhamnod . .	14½	193	—3	—1·55
Nimari M S .	Dhamnod . .	21	193	+15	+7·77
Nimari M V .	Dhamnod . .	17	193	+12	+6·26
Verum 434 .	Dhamnod . .	24	193	+10	+5·18
Malvi 9-15 .	Dhamnod . .	26	193	+25	+12·95
Malvi 9-20 .	Med. land, I. P. I. .	16	189	—7	—3·70
Malvi 9-13 .	Med. land, I. P. I. .	16	189	—5	—2·64
Malvi 9-15 .	Med. land, I. P. I. .	17	189	—7	—3·70
Malvi 9-19 .	Med. land, I. P. I. .	17	189	—5	—2·64
Malvi 9-17 .	Med. land, I. P. I. .	17	189	0	0
Malvi 9-19 .	Kharua . . .	20	189	+3	+1·59
Malvi 9-17 .	Kharua . . .	23	189	+5	+2·64
Malvi 9-13 .	Kharua . . .	25	189	+10	+5·29

TABLE IV—*contd.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1936—contd.					
Malvi 9-20	Kharua	28	189	+10	+5·29
Malvi 9-15	Kharua	33	189	+15	+7·93
Malwa Upland 5	Badnawar	28	189	+35	+18·51
Malwa Upland 4	Badnawar	29	189	0	0
I. H. K. (Upland)	Badnawar	30	189	+10	+5·29
Malwa Upland 2	Badnawar	30	189	+15	+7·93
Malwa Upland 3	Badnawar	34	189	+25	+13·44
Malwa Upland 8 A	Badnawar	42	189	+35	+18·51
Malwa Upland 8 B	Badnawar	43	189	+30	+15·87
1937					
Malvi 43-4	Good land, I. P. I.	20½	157	+5	+3·18
Verum 434	Good land, I. P. I.	26	157	—15	-9·55
Malwa Upland 4	Good land I. P. I.	19	157	0	0
Malwa Upland 3	Badnawar	32	157	+20	+12·74
Malwa Upland 4	Badnawar	27	157	+12	+7·64
Malwa Upland 8 A	Badnawar	34	157	—5	—3·18
Malvi 9-13	I. P. I.	24	156½	+10	+6·39
Malvi 9-20	I. P. I.	20	156½	0	0
Malvi 43-2	I. P. I.	18	156½	—10	—6·39
Malvi 43-4	I.P. I.	22	156½	—20	—12·78
Malvi 43-5	I. P. I.	22	156½	—15	—9·58
Malvi 43-6	I. P. I.	21	156½	—10	—6·39
Malvi 9-13	*Adhan* land, Kharua	23½	156½	+15	+9·58
Malvi 9-20	*Adhan* land, Kharua	24	156½	+25	+15·97

TABLE IV—*concld.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1937—contd.					
Malvi 43-2 .	*Adhan* land, Kharua .	22	156½	—5	—3·19
Malvi 43-4 .	*Adhan* land, Kharua .	24	156½	+20	+12·78
Malvi 43-5 .	*Adhan* land, Kharua .	22	156½	0	0
Malvi 43-6 .	*Adhan* land, Kharua .	22	156½	+5	+3·19
1938					
Indore 1 (Upland)	Med. land, I. P. I. .	29	242	+15	+6·20
Malwa Upland 3	Med. land, I. P. I. .	34	242	+15	+6·20
Malwa Upland 4	Med. land, I. P. I. .	31	242	+10	+4·13
Malwa Upland 8A	Med. land, I. P. I. .	32	242	+5	+2·07
Malvi 43-4 .	Good land, I. P. I. .	16½	270	+2	+0·74
Verum 434 .	Good land, I. P. I. .	21	270	+6	+2·22
Malwa Upland 4	Good land, I. P. I. .	27	270	+3	+1·11
Malvi 43-6 .	Dhar . . .	25	278	—30	—10·79
Malvi 14 .	Dhar . . .	24	278	—25	—8·99
Malvi 22 .	Dhar . . .	26	278	—28	—10·07
Malvi 9-20 .	*Adhan* land, Kharua .	18	278	—5	—1·80
Malvi 43-4 .	*Adhan* land, Kharua .	18	278	—3	—1·07
Malvi 43-5 .	*Adhan* land, Kharua .	18	278	—7	—2·52
Malvi 9-13 .	Med. land, I. P. I. .	24	278	—20	—7·19
Malvi 9-20 .	Med. land, I. P. I. .	22	278	—17	—6·12
Malvi 43-2 .	Med. land, I. P. I. .	22	278	—17	—6·12
Malvi 43-4 .	Med. land, I. P. I. .	21	278	—19	—6·83
Malvi 43-5 .	Med. land, I. P. I. .	21	278	—19	—6·83
Malvi 43-6 .	Med. land, I. P. I. .	22	278	—25	—8·99
Malvi 14 .	Med. land, I. P. I. .	21	278	—19	—6·83
Malvi 22 .	Med. land, I. P. I. .	24	278	—20	—7·19

Table V

Yield per acre for Cambodia and desi *cottons in Malwa, 1934*

Station and type of land	Variety	Yield of *kapas*, lb. per acre	Ginning percentage	Yield of lint, lb. per acre
Med. land, Indore	Malvi 9	383	29·5	113
	Cambodia . . .	195	27·7	54
	Local	346	27·3	94
	Standard error . .	24·6	0·3	
	Significant difference .	74	0·9	
Poor land, Indore .	Malvi 9	219	28·8	63
	Cambodia . . .	117	26·4	31
	Local	214	26·5	57
	Standard error . .	11·5	0·4	
	Significant difference .	35	1·2	
Adhan land, Sitamau	Malvi 9	1187	32·9	390
	Cambodia . . .	652	30·3	197
	Local	1081	30·0	324
	Standard error . .	27·5	. .	
	Significant difference .	82	. .	
Med land, Sitamau .	Malvi 9	367	31·2	114
	Cambodia . . .	247	30·3	75
	Local	349	30·0	105
	Standard error . .	17·3	. .	. .
	Significant difference .	52	. .	. .
Med. land, Badnawar	Malvi 9	347	. .	. .
	Cambodia . . .	242	. .	. .
	Local	413	. .	. .
	Standard error . .	32·6	. .	
	Significant difference .	99	. .	

TABLE VI

Yield per acre for Cambodia and desi *cottons in Malwa, 1935*

Station and type of land	Variety	Yield of *kapas*, lb. per acre	Ginning percentage	Yield of lint, lb. per acre
Adhan land, Badnawar	Malvi 9	473	31·9	151
	Cambodia . . .	400	31·1	124
	Local	444	30·8	137
	Standard error . .	65	0·4	..
	Significant difference .	..	..	..
Adhan land, Kharua	Malvi 9	1027	31·1	319
	Cambodia . . .	946	30·5	288
	Local	967	29·0	280
	Standard error . .	60	0·2	..
	Significant difference .	..	0·6	..
Adhan land, Ratlam	Malvi 9	1912	31·9	610
	Cambodia . . .	1931	30·1	581
	Local	937	29·6	277
	Standard error . .	94	..	..
	Significant difference .	295	..	..
Adhan land, Sitamau	Malvi 9	940	31·6	297
	Combodia . . .	648	31·3	203
	Local	810	32·1	260
	Standard error . .	38	0·4	..
	Significant difference .	120	..	..

TABLE VII

Yield per acre for Cambodia and desi *cottons in competition experiments at Indore, 1935, 1938 and 1939*

Season	Variety	Yield of *kapas*, lb. per acre	Ginning percentage	Yield of lint, lb. per acre
1935	**Malvi 9**	498	33·2	165
	Cambodia	373	31·0	116
	Standard error	26·2	..	..
	Significant difference	88	..	..
1938	**Malvi 9**	366	32·8	120
	Cambodia	525	34·0	178
	Local	522	31·3	163
	Standard error	38·6	..	..
	Significant difference	109	..	..
	Malvi 9	263	33·7	89
	Combodia	235	32·5	76
	Local	301	31·1	94
	Standard error	20·2	..	..
	Significant difference	57	..	..
1939	**Malvi 9**	322	27·0	87
	Cambodia	212	25·0	53
	Local	303	25·8	78
	Standard error	17·5	..	..
	Significant difference	50	..	..

THE EFFECT OF ENVIRONMENT ON FIBRE MATURITY OF COTTON

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(With one text-figure)

INTRODUCTION

ALTHOUGH all changes in plant characters are either environmental or genetical in origin, it was found difficult, in an earlier study of fibre maturity by Gulati and Ahmad [1935], to determine separately the part played by each one of them. The need of further work in this direction being indicated by this work, an extensive study was undertaken with a view to estimating the modifications caused by environmental as distinct from genetical factors. The effect of hybridization on fibre maturity, mean fibre-length and fibre-weight per unit length has since been successfully worked out, and a paper on this subject by Koshal, Gulati and Ahmad [1940] has recently been published. The present paper deals with the second aspect of the study, i.e. fibre maturity in relation to environment, which includes such agronomical factors as preparatory cultivation, locality, sowing date, irrigation, manuring and spacing. So far as is known to the writer this is the first attempt to investigate the effect of these factors on fibre maturity in a systematic manner. The effect of environmental factors on other fibre properties, such as length, weight and strength, has often been observed and studied by previous workers, among whom may be mentioned Burd [1925], Balls [1928] and Barre [1938]. It would be expected that fibre maturity, like other fibre properties, would be affected by agronomical treatments on account of the fundamental property of response to external stimulus possessed by the living protoplasm.

MATERIAL

Two sets of samples which were kindly supplied by the Director, Institute of Plant Industry, Indore, formed the material for this investigation. These samples were grown at Sri Ganganagar (Bikaner) on an experimental scale with the primary object of studying the effect of agronomical treatments on the yield of cotton. The first set dealt with the agronomical factors, two sowing dates (one in May and the other in June), presence and absence of preparatory cultivation, heavy and moderate irrigation, three manurial treatments (two fertilizers and control) and two spacings in relation to two cottons P-A/289F. and Mollisoni. A complete set of this kind would have given 96 differently treated samples, i.e. 48 for each cotton, but as all of them were not available, tests were carried out on 26 samples only. These samples, 19 of which belonged to Mollisoni and seven to P-A/289F, could be arranged in pairs so as to enable comparison of one factor at a time.

The second set which was complete included the following factors :— (1) Three sowing dates : (*a*) 22 March 1936, (*b*) 14 May 1936, and (*c*) 5 July 1936 ; (2) Two irrigations: (*a*) adequate, and (*b*) scanty ; (3) (*a*) Presence and (*b*) absence of basal dressings of manure, and (4) three types of top dressings : (*a*) No manure (T_1), (*b*) Well-rotted sheep-dung manure (T_2) and (*c*) Well-rotted sheep-dung manure *plus* ammonium sulphate (T_3). Under this scheme of agronomical lay-out Cambodia cotton was grown in six Rajputana States; but unfortunately only from two of them (Bundi and Ajmere) enough material was available for all the treatments. The material thus consisted of 72 samples, 36 from each locality.

METHOD

The laboratory technique for determining fibre maturity of cotton has been described by Gulati and Ahmad [1935] and Ahmad and Gulati [1936] previously. The same technique was employed in this study, a notable feature of which was that the samples were tested without any knowledge of their agronomical history so as to preclude all possibilities of personal bias in the results.

RESULTS

The maturity percentages of the various samples belonging to both the sets are presented in Tables I and II. In Table I, the 26 samples of the first set are arranged in pairs such that the effect of the presence or absence of each agronomical factor is compared at a time. The second set is arranged in Table II according to the plan of the experiment. A separate discussion is devoted to each of these sets.

DISCUSSION OF RESULTS

First set

The maturity results of the first set are also shown in Fig. 1, where the 26 values are plotted in descending order of magnitude and according to cottons.

From this diagram it will be readily noticeable that the best combination of agronomical factors is not the same for both P-A/289F and Mollisoni. Whereas May sowing, presence of preparatory cultivation, heavy irrigation, Nicifos manure and single spacing produce the highest maturity value of P-A/289F, June sowing, absence of preparatory cultivation, no manure, moderate irrigation and single spacing help Mollisoni to attain its biggest maturity value. It is interesting to note that the two cottons find their highest maturity values with four opposing agronomical factors out of the five studied.

It will also be noted that the samples showing the highest and the lowest maturity values in each cotton are not treated differently in respect of all the five agronomical factors. In either case it is only a change in two of these factors that appears to be responsible for the maximum variation in the percentage of mature hairs. For P-A/289F a change of 19 in the percentage of mature hairs is found to be due to a change of sowing date and irrigation—May sowing with heavy irrigation yielding the highest value, against June sowing with moderate irrigation yielding the lowest maturity value. In Mollisoni the maximum difference of 16 per cent in maturity was produced again by two factors, namely presence or absence of cultivation and single or double spacing.

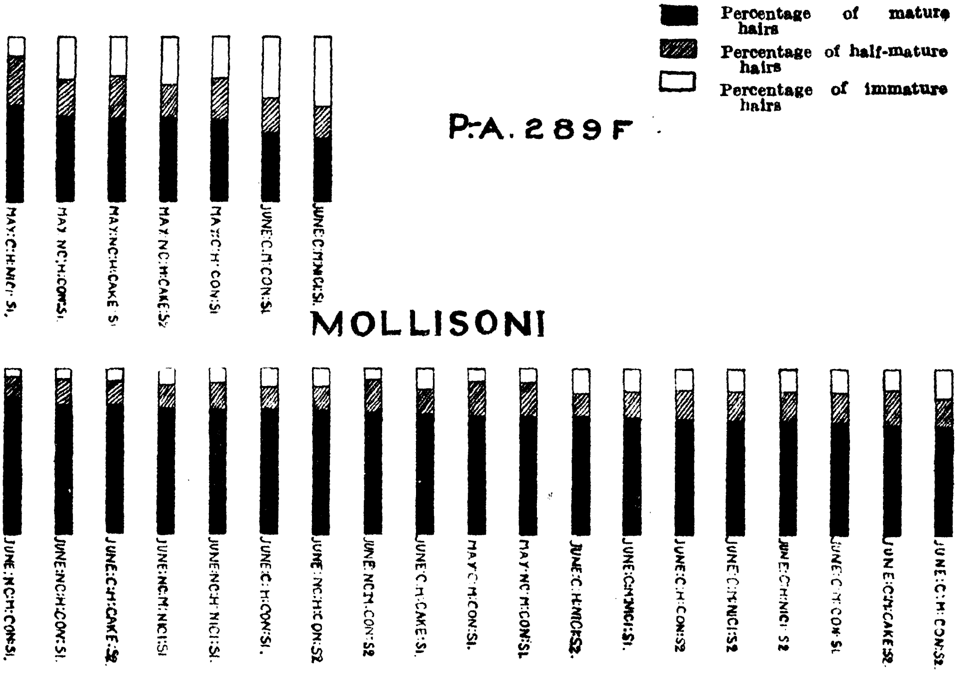

FIG. 1. Maturity results of the first set

May = May sowing; June = June sowing; C = preparatory cultivation; H = heavy irrigation, Nici = Nicifos manuring; S_1 = single spacing; NC = no preparatory cultivation; M = moderate irrigation; Con. = control (no manure); Cake = castor cake; S_2 = double spacing]

The differential response of the two cottons to various agronomical factors and also the importance of early sowing date with heavy irrigation for P-A/289F and the absence of preparatory cultivation with single spacing for Mollisoni, thus, become evident.

The single-factor arrangement in Table I will now be examined in detail. It has been stated already that in this table the results of alternative treatments for each agronomical factor are compared separately.

The reason for adopting such comparisons was that the analysis of variance could not be applied to such incomplete data and the appropriate standard error from the actual data could not be evaluated. However, in such a comparative study we could take avantage of the standard error calculated for different sizes of sample for this fibre property by Gulati and

TABLE I

Maturity results of set 1 arranged in pairs so as to sort out the effect of each agronomical factor

Factors	Percentages			Factors	Percentages			Agronomical treatment
	Mature	Half-mature	Immature		Mature	Half-mature	Immature	
Sowing date								
P-A 289F	...	...	...	P-A 289F	...	...	...	
Mollisoni—				Mollisoni—				
May	71	21	8	June	67	18	15	C : M : Con : S1
Do.	71	20	9	..	82	13	5	NC : M : Con : S1
Preparatory cultivation								
P-A 289F—								
No cultivation	51	23	26	Cultivation	49	25	26	
Mollisoni—								
No cultivation	82	13	5	Cultivation	67	18	15	June : M : Con : S1
Do.	73	20	7	Do.	66	16	18	June : M : Con : S2
Do.	76	14	10	Do.	70	16	14	June : M : Nici : S1
Do.	74	15	11	Do.	69	18	13	June : H : Con : S2
Do.	75	16	9	Do.	71	14	15	June : H : Nici : S1
Do.	78	16	6	Do.	75	14	11	June : H : Con : S1
Do.	71	20	9	Do.	71	21	8	May : M : Con : S1
Irrigations								
P-A 289F—								
Mollisoni—								
Heavy	78	14	8	Moderate	66	21	13	June : C : Cake : S2
Do.	69	18	13	Do.	66	16	18	June : C : Con : S2
Do.	74	15	11	Do.	73	20	7	June : NC : Con : S2
Do.	71	14	15	Do.	70	16	14	June : C : Nici : S2
Do.	68	18	14	Do.	68	18	14	June : C : Nici : S2
Do.	75	16	9	Do.	76	14	10	June : NC : Nici : S1
Do.	78	16	6	Do.	82	13	5	June : NC : Con : S1
Manure								
P-A 289F—								
Cake	50	24	26	Control (no manure)	51	23	26	May : NC : H : S1
Nicifos	39	18	43	Do.	41	21	38	June : C : M : S1
Do.	58	20	12	Do.	49	25	26	May : C :H : S1

TABLE I—*contd*

Factors	Percentages			Factors	Percentages			Agronomical treatment
	Mature	Half-mature	Immature		Mature	Half-mature	Immature	
Mollisoni—								
Cake	78	14	8	Control (no manure)	69	18	13	June : C : H : S2
Do.	66	21	13	Do. . .	66	16	18	June : C : M : S2
Do.	72	15	13	Do. . .	75	14	11	June : C : H : S1
Do.	78	14	8	Nicifos . . .	68	18	14	June : C : H : S2
Do.	72	15	13	Do. . . .	71	14	15	June : C : H : S1
Do.	66	21	13	Do. . . .	68	18	14	June : C : M : S2
Nicifos. . .	76	14	10	Control (no manure)	82	13	5	June : NC : M : S1
Do.	71	14	15	Do. . .	75	14	11	June : C : H : S1
Do.	75	16	9	Do. . .	78	16	6	June : NC : H : S1
Do.	68	18	14	Do. . .	69	18	13	June : C : H : S2
Do.	68	18	14	Do. . .	66	16	18	June : C : M : S2
Do.	70	16	14	Do. . .	67	18	15	June : C : M : S1
Spacings								
P-A 289F— . .								
Single . . .	50	24	26	Double . . .	50	21	29	May : NC : H : Cake
Mollisoni—								
Single . . .	82	13	5	Double . . .	73	20	7	June : NC : M : Con
Do.	75	14	11	Do. . . .	69	18	13	June : C : H : Con
Do.	78	16	6	Do. . . .	74	15	11	June : NC : H : Con
Do.	71	14	15	Do. . . .	68	18	14	June : C : H : Nici
Do.	70	16	14	Do. . . .	68	18	14	June : C : M : Nici
Do.	67	18	15	Do. . . .	66	16	18	June : C : M : Con
Do.	72	15	13	Do. . . .	78	14	8	June : C : H : Cake

H = Heavy irrigation (eleven waterings)
M = Moderate irrigation (six waterings)
Con = Control or no manure
Cake = Castor-cake at 30 lb. N per acre
Nici = Nicifos 22/18 at 30 lb. N per acre
S1 = 6 in. plant-to-plant spacing
S2 = 12 in. plant-to-plant spacing
C = With preparatory cultivation
NC = Without preparatory cultivation

NOTE.—The following crops were previously grown without manuring on the land used for the setests:—

Season	Crop
Kharif 1932	**Fallow**
Rabi 1932-33	**Wheat**
Kharif 1933	**Fallow**
Rabi 1933-34	**Wheat**

Ahmad [1935]. According to this, the maximum sampling error for a sample of 500 fibres, as was tested for each sample under discussion, is 8·9 for $P=0\cdot05$. Any difference exceeding this value is, therefore, tentatively regarded as signifiant in the following discussion.

(*a*) *Sowing date.*—The effect of this factor could be isolated for Mollisoni only, two pairs of values being available for the purpose. In the first pair the differences in maturity percentages are not significant, but they are so in the second. June sowing yields higher percentage of mature hairs than May sowing. In order to see why June sowing failed to produce a similar trend in the first pair also, it is necessary to take into account the other agronomical treatments received by either pair of samples. Looking at these treatments from the last column in Table I, it is found that the two pairs differ from each other only in respect of presence or absence of preparatory cultivation. Presence of preparatory cultivation appears to nullify the effect of June sowing in the first pair, while its absence heightens the effect of June sowing in the second pair. It is, therefore, concluded that June is a favourable time for sowing Mollisoni, but only in the absence of preparatory cultivation.

(*b*) *Preparatory cultivation.*—The presence or absence of this factor did not affect the maturity of P-A/289F in the one pair of samples available for the purpose.

For Mollisoni, out of seven pairs available for the study of this factor, six show a trend of higher maturity for samples without preparatory cultivation than those grown with preparatory cultivation. It is only in one of the six pairs showing the superiority of the absence of preparatory cultivation that there is a significant increase in the percentage of mature hairs over the corresponding sample grown after the preparatory cultivation. The differences in the remaining five pairs are non-significant. The similarity of the trend in six pairs, however, indicates a preponderating effect of the absence of preparatory cultivation. The maturity percentages in the seventh pair are similar for the opposing treatments. A perusal of the last column of Table I again shows that the different behaviour of this pair is associated with its being May sown, while all others are June sown. The absence of preparatory cultivation is thus observed to be beneficial to the maturity of Mollisoni when it is June sown.

(*c*) *Irrigation.*—Like sowing date, this factor was not represented alone in the available samples of P-A/289F. However, in an earlier part of the discussion it has been noticed already that a combination of May sowing with heavy irrigation gave the highest value, while June sowing with moderate irrigation yielded the lowest maturity value for P-A/289F.

As regards Mollisoni there are seven pairs of samples. Four of these pairs bring out a trend of higher maturity for heavy irrigation ; two pairs indicate the opposite trend of superiority of the moderate irrigation and in one pair the two types of irrigation yield similar values. Among the four pairs showing higher percentages of mature hairs for heavy irrigation, significant improvement in maturity is noticed only in one pair. It is in this pair, therefore, that the effect of heavy irrigation is least eclipsed by other factors, while the interactions with other factors appear to lower the good effect of this treatment.

The conclusion from this study is that heavy irrigation under certain conditions is beneficial to both the cottons. Afzal [1937] also found that maturity generally increased with irrigations in the case of P-A/4F.

(*d*) *Manures.*—The effect of Nicifos and cake maures is compared to no-manure in three pairs for P-A/289F. Nicifos yields significantly higher maturity values than no-manure in one case, but not in the other. The differential response of the two pairs is again found to be associated with different sowing dates. Nicifos proved useful when applied with May sowing, but not with June sowing. The application of cake made no difference from no-manure in the third pair of P-A/289F.

Mollisoni presented 12 pairs of samples for this study. Comparisons between cake and Nicifos, and cake and no-manure are available in three pairs for each. The application of cake scored a significantly higher maturity than Nicifos or no-manure in one of the three pairs for each, but its effect varied non-significantly in the other two pairs. Nicifos is compared with no-manure in the remaining six pairs. In four of these, no-manure showed a trend of higher maturity than Nicifos, evidently due to the beneficial superimposing effect of heavy irrigation in three of them, and in the fourth due to a similar effect of the absence of cultivation. The effect of Nicifos rises above that of no-manure in the remaining two pairs, but on account of the differences being non-significant, the cause of noted variation cannot be ascribed with any certainty.

The above discussion brings out the beneficial effect of Nicifos to P-A/289F and of cake and no-manure to Mollisoni in suitable combinations with other factors.

(*e*) *Spacings.*—P-A/289F is again represented by one pair for this study. The two kinds of spacings do not lead to any difference in the maturity percentages of the two samples in the pair. In Mollisoni out of seven pairs, six show a trend of higher maturity for single than for double spacing. The differences are again significant only in one of these pairs and not in others. In the seventh pair, although the differences are also non-significant, the trend goes in the opposite direction, i.e. double spacing leading to a somewhat maturer cotton than single spacing. Cake manure appears to be the second helpful factor in this pair. On the whole, single spacing is more useful than double spacing to Mollisoni, although P-A/289F did not react to the influence of spacing in the studied pairs of samples.

It must, however, be mentioned that conclusions in the above comparisons are based on a few or even single pair of values and hence cannot be recommended for wider application.

Second set

Table II shows the maturity percentages of the samples of Cambodia (Indore) cotton grown at Bundi and Ajmere which comprise set 2 of the material mentioned before.

It should be mentioned here that though Cambodia cotton is familiarly associated with South India, it is also fairly widely grown in Central India. These results, therefore, while having a general appeal for workers on agrotnomy of cotton, should prove especially useful to cotton cultivators in Central India.

TABLE II

Maturity results of set 2

Agronomical treatments*				Bundi			Ajmere		
Sowing date	Irrigation	Basal dressing	Top dressing	Mature (per cent)	Half-mature (per cent)	Immature (per cent)	Mature (per cent)	Half-mature (per cent)	Immature (per cent)
March	Adequate	No B	T1	49	35	16	63	20	17
			T2	57	28	15	62	23	15
			T3	69	20	11	66	22	12
		B	T1	57	28	15	56	25	19
			T2	58	25	17	68	22	10
			T3	63	24	13	59	25	16
	Scanty	No B	T1	62	24	14	70	20	10
			T2	68	21	11	64	24	12
			T3	62	27	11	66	22	12
		B	T1	54	34	12	61	22	17
			T2	58	30	12	66	24	10
			T3	53	37	10	60	28	12
May	Adequate	No B	T1	54	31	15	64	21	15
			T2	63	27	10	59	28	13
			T3	66	22	12	65	26	9
		B	T1	61	29	10	66	20	14
			T2	58	27	15	66	21	13
			T3	57	28	15	67	19	14
	Scanty	No B	T1	57	30	13	60	25	15
			T2	55	32	13	56	31	13
			T3	63	29	8	62	25	13
		B	T1	52	34	14	60	23	17
			T2	48	37	15	60	21	19
			T3	60	26	14	60	24	16
July	Adequate	No B	T1	53	27	20	64	21	15
			T2	67	21	12	64	23	13
			T3	72	19	9	69	20	11
		B	T1	48	38	14	60	21	19
			T2	52	36	12	61	23	16
			T3	58	26	16	66	17	17
	Scanty	No B	T1	47	29	24	58	25	17
			T2	46	40	14	61	23	16
			T3	46	36	18	61	26	13
		B	T1	42	34	24	53	32	15
			T2	41	40	19	51	30	19
			T3	55	26	19	67	22	11
		Total	...	2,031	1,057	512	2,241	844	515
		Mean (per cent)	...	57	29	14	62	24	14

---

* **Adequate = Irrigation at 15 days interval** during the hot weather and one or two **irrigations after rains at suitable intervals**

Scanty = One or two irrigations at start for germination followed by irrigation frequency to prevent wilting of the crop; one or two post-rain irrigations as in adequate

B = Basal dressing of well-rotted sheep-dung manure at 32 mds. per acre and ammonium sulphate at 50 lb. per acre

No B = No basal dressing

T1 = No top dressing

T2 = Top dressing of sheep dung at 32 mds. per acre

T3 = Top dressing of sheep dung at 32 lb. per acre and ammonium sulphate at 50 lb. per acre supplied **mixed together after the mixture** had been allowed to stand for five days

Top dressings were given after the rains were established, but not before the 3rd week of July

As the experiment was well planned and the samples from all the treatments were available, analysis of variance could be applied to the data. Variance due to each factor included in the experiment could, thus, be sorted out and studied. The results of this analysis are given below :—

Analysis of variance

(Per cent mature hairs)

Agronomical factors	Degrees of freedom	Sum of squares	Mean square	*F*
A.—Average effect—				
(*L*) Localities . . .	1	612·5	612·5	33·40**
(*S*) Sowing dates . .	2	261·5	130·8	7·13**
(*I*) Irrigations . . .	1	280·0	280·0	15·27**
(*B*) Basal dressings . .	1	156·0	156·0	8·51**
(*T*) Top dressings . .	2	319·0	159·5	8·70**
B.—First order interactions*—				
$L \times S$	2	90·3	45·2	2·46
$L \times I$	1	26·9	26·9	1·47
$L \times B$	1	43·6	43·6	2·38
$L \times T$	2	63·6	31·8	1·73
$S \times I$	2	317·3	158·7	8·65**
$S \times B$	2	46·0	23·0	1·25
$S \times T$	4	147·5	36·9	2·01
$B \times I$	1	8·7	8·7	0·47
$B \times T$	2	21·7	10·8	0·59
$I \times T$	2	50·3	25·2	2·37
Residual	45	825·1	18·3	

* Since there was no replication, the higher-order interactions together were considered as residual in the above analysis.

** Denote 1 per cent point of significance.

It will be noted that the variance due to each of the five factors is significant at 1 per cent level [Snedecor, 1937], showing that each factor is capable of modifying the maturity of this cotton to an appreciable extent. From the first-order interactions, only that between sowing date and irrigation has a significant variance, while all others are non-significant. The absence of significance for the other interactions suggested that most of these factors have no differential effect upon the maturity of the fibre.

Each factor is discussed below in greater detail.

(*a*) *Locality.*—The average maturity values from the two localities yield significantly different maturity percentages—Ajmere producing more mature cotton than Bundi.

Locality	Mature	Half-mature	Immature
Ajmere	62	24	14
Bundi	57	29	14

Standard error ± 0·71

(*b*) *Sowing date.*—Out of the three sowing dates—March, May and July—March yields the highest maturity percentages and July the lowest. The trend is noticeable in both the localities, although the fall in maturity from May to July is significant in Bundi and not in Ajmere.

Locality	Percentage of mature hairs		
	March	May	July
Bundi	59	58	52
Ajmere	63	62	61

Standard error ± 1·23

(*c*) *Irrigation.*—Adequate irrigation was found to produce higher percentages of mature hairs as compared with scanty irrigation in both the localities in May and July sowings, but in March this was not the case as will be seen from the mean values given below. In other words, with the benefits of early sowing even scanty irrigation served the purpose so far as fibre maturity is concerned, but with late sowing heavier irrigation was necessary to give a sufficiently high fibre maturity. It was due to this differential effect in respect of sowing dates and irrigation that the interaction $S \times I$ had a significant variance value.

It may be emphasized that the final effect of irrigation on any crop must be judged in relation to the rainfall record of the season in question. Here, for instance, it is found that the March-sown crop gets the benefit of local rains during the maturation period equally for both adequate and scanty irrigations, leading to almost similar maturity values. But the later crops, i.e. May and July sown get the monsoon rains during their vegetative phase of growth and, hence, the two types of irrigation after the rains affect the maturity of the lint of the crop differentially.

Percentage mature hairs

Sowing date	Bundi		Ajmere	
	Adequate	Scanty	Adequate	Scanty
March	59	59·5	62	64·5
May	60	56	64·5	60
July	58	46	64	58·5

Standard error ± 1·75

(*d*) *Basal dressings.*—A comparison of basal dressing with no basal dressing shows that the latter is on the whole better than the former for obtaining maturer cotton. The effect again is significant at Bundi but not at Ajmere. Mean values for these treatments are given below :—

Percentage mature hairs

Locality	No B	B
Bundi	59	54
Ajmere	63	62

Standard error ± 1·01

(*e*) *Top dressing.*—The three treatments considered under this head are :—T_1 or no top dressing, T_2 or top dressing with sheep dung, and T_3 or top dressing with sheep dung and ammonium sulphate. The average muturity for T_1 is found to be the lowest, while that for T_3 is the highest at both the places as seen below :—

Percentage mature hairs

Locality	T_1	T_2	T_3
Bundi	53	56	60
Ajmere	61	61·5	64

Standard error ± 1·23

The improvement affected by T_3 is noteworthy as it persists not only with localities but also with respect to sowing date, irrigation and basal dressings.

Percentage mature hairs

Sowing date	Agronomical factor		
	T₁	T₂	T₃
March	59·0	62·6	62·2
May	59·2	58·1	62·5
July	53·1	55·4	61·8

Standard error ± 1·51

Irrigation	T₁	T₂	T₃
Adequate	57·9	61·2	64·8
Scanty	56·3	56·2	59·6

Standard error ± 1·23

Basal dressing	T₁	T₂	T₃
No B	58·4	60·2	64·3
B	55·8	57·3	60·4

Standard error ± 1·23

It is therefore suggested that top dressing of sheep dung and ammonium sulphate may be used on a larger scale for improving the fibre maturity of cottons of Cambodia type wherever necessary. It would be interesting to perform well-designed experiments to confirm this conclusion and to extend it to other cottons. It may be pointed out here that, whereas the application of basal dressing of sheep dung with ammonium sulphate did not prove helpful in improving fibre maturity, the application of sheep dung and ammonium sulphate as top dressing, after the rains were well established, improved the maturity of this cotton. The usefulness of top dressing of manure to cotton yield has been previously shown by Wells [1928]. The effectiveness of the manure used in the present experiment in top dressing and not in basal dressing appears to be due to the movement of sulphate of ammonia in the soil. Sahasrabudhe and Gokhale [1934] found that this salt diffuses in the soil through an equal distance on all sides (6 in. in six weeks) ; but the quantity diffused is greater in the downward direction and smaller in the upward direction than along the horizontal. This would explain how more of it may be available to the root-system of cotton plant from the top dressing than from the basal dressing.

SUMMARY

The effect of environment, as provided by agronomical factors, on fibre maturity of cotton, for which material was kindly supplied by the Institute of Plant Industry, Indore, is described in this paper.

The material consisted of two sets of samples. The first set consisted of samples of P-A/289F and Mollisoni cottons grown at Sriganganagar (Bikaner). The agronomical factors included in this experiment were: (*i*) Sowing dates in May and June, (*ii*) presence and absence of preparatory cultivation, (*iii*) heavy and moderate irrigations, (*iv*) cake, Nicifos and no-manure, and (*v*) 6 and 12 in. spacings. From a study of these results the following conclusions are drawn, which should be regarded as tentative owing to the small number of samples in this set :—

(1) Out of the two sowing dates, May suited P-A/289F, while June helped Mollisoni to attain its highest fibre maturity.

(2) Preparatory cultivation did not prove beneficial to either of the two cottons in respect of fibre maturity. Its absence, however, helped Mollisoni when it is June sown.

(3) Heavy irrigation comprising 11 waterings as compared to moderate irrigation of 6 waterings was helpful in raising the fibre maturity of both the cottons. Heavy irrigation with May sowing formed a good combination for P-A/289F.

(4) The application of Nicifos to P-A/289F was evidently better than no-manure when the cotton was sown in May, while cake and no-manure suited Mollisoni better than Nicifos.

(5) Six inch spacing as compared with 12 inch spacing improved the fibre maturity of Mollisoni.

The second set consisted of samples of Cambodia cotton grown in two Rajputana States—Bundi and Ajmere. The agronomical factors studied in this experiment were : (*i*) three sowing dates in March, May and July, (*ii*) adequate and scanty irrigations, (*iii*) presence and absence of basal dressing of manure, and (*iv*) three top dressings of manure. The following conclusions are drawn from the results :—

(1) Locality has a significant effect upon maturity percentage, Ajmere yielding higher percentages of mature fibres as compared with Bundi.

(2) The earlier-sown samples gave higher percentages of maturity in both the localities. Thus, sowing in March proved the best and sowing in July the worst in respect of this property. The bad effects of late sowing could, however, be remedied by heavy irrigation.

(3) Adequate irrigation yielded higher fibre maturity than scanty irrigation.

(4) The application of sheep dung at the rate of 32 mds. per acre *plus* ammonium sulphate at the rate of 50 lb. per acre as basal dressing had a depressing effect upon fibre maturity as compared with no basal dressing.

(5) Top dressings with sheep dung alone (T_2) and sheep dung *plus* ammonium sulphate (T_3) as compared to no top dressing (T_1) had a beneficial effect upon maturity percentage, T_3 giving better results than T_2. Thus, the application at the same rate of the same manure, i.e. sheep dung *plus* ammonium sulphate did not prove beneficial as a basal dressing, but proved beneficial when applied as a top dressing.

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REFERENCES

Afzal, M. (1937). *First Conference of Scientific Research Workers on Cotton in India*, p .92
Ahmad, N. and Gulati, A. N. (1936) *J. Text. Inst.* **27**, T109-T111
Balls, W. L. (1928). *Studies of quality in cotton*: MacMillan & Co. Ltd., London, pp. 292-7
Barre, H. W. (1938). *Text Res.* **8**, 317-22
Burd, L. H. (1925). *Emp. Cotton Grow. Rev.* **2**, 225-36
Gulati, A. N. and Ahmad, N. (1935). *J. Text Inst.* **26**, T261-T292 (also *I. C. C. C. Tech. Bull. Series B*, No. 20)
Koshal, R. S.; Gulati, A. N. and Ahmad, N. (1940). *Indian J. agric. Sci.* **10**, 975-89
Sahasrabudhe, D. L. and Gokhale, D. H. (1934). *Indian J. agric. Sci.* **4**, 121-46
Snedecor, G. W. (1937). *Statistical methods*: Collegiate Press Inc. Ames, Iowa, pp. 174-7
Wells, W. G. (1928-29). *Empire Cotton Growing Rept. from Expt. Sta.*, pp. 1-28

GROWTH STUDIES IN RICE

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INTRODUCTION

ENGLEDOW [1923, 1924, 1926, 1928, 1930] in a series of valuable articles relating to growth, development and yield in the wheat plant in England stressed the importance of early tiller formation as an index of high-yielding capacity in a variety. Further, he discovered that there is what he termed a critical period in tillering which marks the time up to which spacing does not influence tillering and before which are formed those tillers that survive to harvest and bear ears.

Joshi [1923] gave an account of the effects of environmental factors on growth and tillering in rice in the Bombay province, while Bhide [1927] in Bombay also expressed growth in rice in terms of height of plant.

Ramiah and Narasimham [1936] described several phases of growth in the rice plant under Madras conditions, and Rao [1937] published data showing correlation of some characters, including tillering, on yield in rice in Madras.

Growth studies were carried out as part of the programme of work during the five-year period of a grant from the Imperial Council of Agricultural Research for rice research in Burma, the main object being to find out the different phases of growth and development in the rice plant and whether there is a critical period in tillering as in the case of wheat. The importance of tillering in connection with yield in cereals is generally recognized, and this article, which gives a summary of the earlier results of growth studies in rice under Lower Burma conditions, has been written at the request of the Imperial Council of Agricultural Research.

The studies were conducted on the Rice Research Station at Hmawbi in Lower Burma, where the crop is rain-fed and grown during the period of the south-west monsoon. The rainfall on the Station averages about 96 in. per annum, and almost the whole of this rainfall is from May till November, the highest precipitation being in the months of July and August. The soil consists of a stiff alluvial clay, the *p*H value being 6·1 for the soil and 35 for the sub-soil. The average yields are about 1,600 lb. of paddy to the acre.

METHOD

For the experiment, one half-acre plot of average fertility was used and random samples were taken from two pure lines, A16-34 and C15-10, in 1933 and from three pure lines, A16-34, C19-26 and C15-10, in 1934. The pure line A16-34 is early maturing, C19-26 is intermediate and C15-10 is late maturing. The seedlings were raised in nurseries in the usual way and transplanted at the age of 35 days. Planting was carried out in rows at two different spacings of 8 in. by 8 in. (close spacing) and 18 in. by 18 in. (wide spacing) for each pure line, the end and side rows being left out of the experiment to eliminate border effects. The close spacing is about the normal under ordinary cultivation conditions, while the wide spacing is used on plant breeding areas where individual plants have to be examined.

Thirty-six samples of four plants each were taken at random for study from each pure line for each spacing, except in the year 1933, when 32 samples only were taken in wide spacing in A16-34 and C15-10. The main stems were labelled by means of small zinc tags at the time of planting, and the tillers when they appeared above ground level were also labelled by small zinc tags so that growth and development of the main stems and tillers could be studied and the flowering dates and final yield of grain per tiller compared with the date of tiller formation. By this means it was also possible to record the death rate in tillers according to the date of tiller formation.

Data were recorded weekly from the 1st week of August onwards till the pure lines were harvested, and further data were recorded in the laboratory after the plants and grain were thoroughly sun-dried.

TILLERING

Tiller formation

In Table I are shown the average number of tillers formed at different dates in each pure line for each spacing over two years in the case of A16-34 and C15-10 and for one year in the case of C19-26. The percentages of tillers formed that survived, the percentage contributions of tillers formed at different dates to the final stem population and the percentage contributions by different tillers to the final yield of grain are also shown. In that Table the letters A, S, O, N represent the months of August, September, October and November respectively, while the numbers at the base of these letters represent the week of the month in which data were recorded. M denotes the main stem.

Tillering commenced about a fortnight after transplanting and continued fairly rapidly in lateral branching order till about the first week of September in close planting, and then it slowed down rapidly. In the first year of the experiment tillering continued rapidly in wide spacing till about the second week of September, but in the second year it continued till about the third week of October, and this may be explained by the fact that the plants in the second year of the experiment received a check in growth early in the growing season on account of heavy rains accompanied by strong winds. In wide planting, a few tillers continued to be formed up till about ten days before flowering, that is, from five to six weeks before ripening, but the quantity of filled grain on these late tillers was very small.

TABLE

Average number of main stems and

Spacing	Strain		M	A_1	A_2	A_3
Close (8 in. × 8 in.)	A 16-34	Tillers formed (includes main stems) . . .	144·00	1·00	15·00	83·00
		Percentage of tillers that survived . . .	90·00	...	90·00	89·00
		Percentage to show the constitution of whole stem population at harvest	28·00	...	3·00	16·50
		Percentage yield in grain	34·66	...	2·98	15·63
	C 15-10 .	Tillers formed (includes main stems) . . .	144·00	27·00	123·50	175·00
		Percentage of tillers that survived . . .	84·00	88·00	78·50	76·50
		Percentage to show the constitution of whole stem population at harvest	22·00	4·00	18·00	24·00
		Percentage yield in grain	29·63	...	19·68	23·98
	C 19-26 .	Tillers formed (includes main stems) . . .	144·00	5·00	52·00	86·00
		Percentage of tillers that survived . . .	62·00	60·00	50·00	57·00
		Percentage to show the constitution of whole stem population at harvest	29·00	1·00	8·00	19·00
		Percentage yield in grain	39·00	...	7·85	21·20
Wide (18 in. × 18 in.)	A 16-34	Tillers formed (includes main stems) . . .	136·00	1·00	13·50	69·00
		Percentage of tillers that survived . . .	94·50	...	85·00	81·50
		Percentage to show the constitution of whole stem population at harvest	12·50	...	1·00	4·50
		Percentage yield in grain	15·60	...	...	5·86
	C 15-10	Tillers formed (includes main stems) . . .	136·00	18·00	80·50	135·50
		Percentage of tillers that survived . . .	43·00	76·00	75·50	79·00
		Percentage to show the constitution of whole stem population at harvest	8·00	0·50	4·00	7·00
		Percentage yield in grain	10·63	...	4·72	8·05
	C 19-26	Tillers formed (includes main stems) . . .	144·00	...	22·00	66·00
		Percentage of tillers that survived . . .	74·00	...	73·00	59·0
		Percentage to show the constitution of whole stem population at harvest	15·00	...	2·00	6·00
		Percentage yield in grain	21·93	...	...	7·51

I

tillers for the years 1933 and 1934

A_4	S_1	S_2	S_3	S_4	S_5	O_1	O_2	O_3	O_4	N_1	N_2
129·00	144·50	42·50	25·00	35·00	17·00	16·50	11·50	2·00	...	...	...
74·50	27·50	51·00	21·00	26·50	18·00	16·00	21·50	...	...	...	...
22·00	17·50	4·50	2·00	3·50	1·00	1·50	1·00	...	...	...	...
23·16	13·58	3·59	1·73	3·02	0·49	0·73	0·49	...	...	...	...
176·50	187·50	38·50	20·00	10·50	17·50	18·50	14·00	8·00	9·00	4·00	0·50
50·50	27·50	30·00	11·50	14·00	16·00	19·00	18·50	12·50	11·50	...	...
16·00	9·00	2·00	0·50	0·50	1·00	1·50	1·00	...	0·50	...	...
14·25	7·50	1·45	0·24	0·32	0·89	1·05	0·81	0·16	...	...	...
106·00	114·00	20·00	14·00	15·00	43·00	41·00	28·00	7·00	4·00	4·00	...
57·00	26·00	25·00	21·00	20·00	23·00	24·00	32·00	14·00	...	...	...
20·00	10·00	2·00	1·00	1·00	3·00	3·00	3·00	...	...	...	...
18·57	6·65	...	...	...	2·32	2·32	2·09	...	...	...	...
118·00	201·00	198·00	168·50	234·00	120·50	130·50	102·50	30·00	26·50	3·50	...
84·00	81·50	80·00	80·00	72·50	69·00	58·00	61·50	26·50	4·00	...	...
8·00	14·50	12·50	12·00	12·00	8·00	7·00	5·50	2·00	0·50	...	...
9·93	17·00	12·97	11·75	10·89	6·77	4·63	3·41	1·16	...	...	...
178·50	321·00	195·00	161·50	229·50	161·00	229·00	142·00	128·50	158·50	118·50	38·00
74·50	75·00	70·00	68·00	65·50	60·00	52·00	46·50	57·00	33·50	9·50	4·50
8·50	15·50	8·50	7·50	10·00	7·00	7·50	4·50	5·00	4·50	1·50	0·50
10·22	16·97	8·90	7·27	9·91	7·13	6·26	3·29	3·28	2·08	0·80	...
77·00	142·00	54·00	64·00	111·00	119·00	122·00	107·00	79·00	82·00	62·00	12·00
61·00	61·00	50·00	56·00	59·00	58·00	41·00	51·00	62·00	50·00	18·00	17·00
7·00	12·00	4·00	5·00	9·00	10·00	7·00	8·00	7·00	6·00	2·00	...
8·12	15·73	4·03	5·85	9·93	9·62	5·03	5·90	4·11	2·24	...	...

In both wide and close spacing, the number of tillers formed in the pure line C15-10 was greater by more than 50 per cent than in A16-34. The pure line C15-10, though it is late in maturing, commenced to produce tillers earlier than the earliest strain, A16-34, and also at a greater rate. The pure line C19-26 also commenced to produce tillers earlier and at a greater rate than A16-34. These data therefore indicate: (1) that good tillering is associated with the early production of tillers and (2) that tillering is not influenced by spacing only and varietal differences play an important rôle.

Death rate in tillers

The data in Table I indicate that the death rate is very much higher in the late-formed than in the early-formed tillers. In close spacing, in all the pure lines, the main stems, with the tillers formed up to the first week of September, constituted the bulk of the final stem population in the samples as those formed after that date only constituted from 7 to 14 per cent. In wide spacing, the later-formed tillers constituted a much larger proportion of the final stem population than in close spacing, and effective tillering in this case continued up till about the third week of October. The data do not indicate that there is a well-defined critical period for tillering in rice under Lower Burma conditions, but they indicate clearly, in the close spacing, the important contributions of tillers formed up to about the first week of September to the final stem population. In tillers formed from that time onwards the death rate is also much higher than in early-formed tillers and in main stems. In wide spacing, effective tillering continued till about the third week of October.

YIELDS

In Table II are shown the average yields, lengths of the panicles and percentages of fully filled grain from main stems and from tillers formed at different dates. The percentages of fully filled grain were worked out on account of the importance of evenness in the size of grain in Burma, particularly for export to high grade markets, and a feature of the results is that the percentages of fully filled grain are smaller than may be expected even on the main stems, although the percentages on main stems are higher than on the later-formed tillers.

In all cases, the panicles on the main stems and early tillers were longer than in the later tillers, and the percentages of filled grain and also the weights of grain were higher in the main stems and early tillers than on late tillers. The rates of decrease in the length of panicle were proportionately less than in the weight of grain per panicle, thus showing that the density of the panicle on later-formed tillers was much less than on early-formed tillers.

The data in Table I show that in close spacing the main stems, together with the tillers formed up till the second week in September, contributed 90 per cent to the yield in A16-34, 93 per cent in C19-26 and 95 per cent in C15-10. In wide spacing, the main stems, together with the tillers formed up till the second week of September, contributed only 62 per cent to the final yield in A16-34, 54 per cent in C19-26 and 52 per cent in C15-10 as effective tillering in this case continued till about the third week of October.

TABLE II

Average yields, lengths of panicle and percentages of fully filled grain from main stems and tillers

Spacing	Strain	Stems	Length of panicle in cm.		Filled grain (per cent)		Yield of filled grain per panicle in gm.	
			1933	1934	1933	1934	1933	1934
Close (8 in. × 8 in.)	A 16-34	M .	25·43± ·10	25·13± ·14	76	80	3·29± ·05	3·38± ·05
		A_2 .	25·60± ·25	...	78	...	3·25± ·07	...
		A_3 .	24·26± ·13	23·58± ·21	76	82	2·78± ·05	2·74± ·08
		A_4 .	24·30± ·14	22·77± ·20	75	82	2·73± ·04	2·41± ·07
		S_1 .	22·36± ·15	23·15± ·17	74	79	2·03± ·04	2·26± ·06
		S_2-S_4 .	23·12± ·31	22·89± ·23	73	70	2·04± ·07	2·35± ·07
		O_1-O_3 .	...	20·36± ·41	...	67	...	1·35± ·11
	C 15-10	M .	26·05± ·08	25·24± ·10	85	77	3·12± ·03	2·97± ·05
		A_2 .	25·19± ·27	23·55± ·14	88	71	2·91± ·05	2·25± ·05
		A_3 .	25·29± ·13	22·59± ·14	85	70	2·73± ·04	1·94± ·05
		A_4 .	23·82± ·14	22·32± ·17	86	71	2·28± ·04	1·89± ·06
		S_1 .	22·75± ·18	21·99± ·19	82	65	2·04± ·05	1·74± ·08
		S_2-O_4 .	22·26± ·37	21·55± ·13	81	67	1·90± ·10	1·53± ·06
	C 19-26	M .	...	27·37± ·19	...	76	...	3·68± ·08
		A_2 .	...	24·24± ·31	...	74	...	2·54± ·11
		A_3 .	...	25·66± ·25	...	77	...	3·07± ·08
		A_4 .	...	24·71± ·27	...	71	...	2·60± ·09
		S_1 .	...	22·40± ·36	...	69	...	1·86± ·11
		S_2-S_3 .	...	22·58± ·22	...	67	...	1·95± ·10
	A 16-34	M .	27·01± ·11	26·49± ·16	75	76	3·85± ·05	2·97± ·06
		A_3 .	27·10± ·16	25·60± ·43	71	79	3·52± ·04	3·15± ·13
		A_4 .	26·73± ·11	25·62± ·21	72	80	3·47± ·05	3·13± ·08
		S_1 .	26·55± ·14	25·47± ·16	73	78	3·40± ·05	2·89± ·06
		S_2 .	25·69± ·13	24·68± ·20	69	78	2·90± ·06	2·63± ·07
		S_3 .	24·86± ·19	24·90± ·17	67	76	2·61± ·06	2·54± ·06
		S_4 .	23·85± ·16	24·45± ·15	63	74	2·21± ·05	2·43± ·05
		S_5 .	23·33± ·17	...	64	...	2·01± ·06	...
		O_1 .	22·40± ·14	23·58± ·19	61	69	1·79± ·05	2·16± ·06
		O_2 .	21·47± ·20	22·10± ·21	59	64	1·59± ·07	1·72± ·05
		O_3 .	...	21·69± ·22	...	54	...	1·51± ·06
		O_4 .	...	21·42± ·18	...	50	...	1·33± ·06
		M .	28·63± ·08	25·73± ·13	85	84	4·07± ·04	3·54± ·06
		A_2 .	27·01± ·11	24·25± ·16	86	81	3·69± ·05	2·91± ·09
		A_3 .	26·56± ·12	24·36± ·19	83	81	3·67± ·06	3·04± ·09
		A_4 .	26·46± ·12	25·30± ·12	85	82	3·54± ·05	3·25± ·06
		S_1 .	25·98± ·12	24·63± ·13	82	77	3·30± ·05	2·86± ·05

TABLE II—*contd*

Spacing	Strain	Stems	Length of panicle in cm.		Filled grain (per cent)		Yield of filled grain per panicle in gm.	
			1933	1934	1933	1934	1933	1934
Wide 18 in. × 18 in.)	C 15-10	S_2 .	25·94± ·10	23·87± ·20	81	73	3·27± ·06	2·47± ·09
		S_3 .	24·80± ·14	24·00± ·16	82	75	2·91± ·07	2·56± ·07
		S_4 .	24·52± ·13	24·00± ·12	78	78	2·69± ·06	2·74± ·06
		S_5 .	23·40± ·19	...	75	...	2·31± ·06	...
		O_1 .	23·28± ·16	24·14± ·11	74	69	2·28± ·06	2·50± ·06
		O_2 .	22·22± ·17	23·47± ·14	70	69	1·89± ·07	2·30± ·07
		O_3 .	21·77± ·13	23·99± ·16	55	68	1·39± ·07	2·30± ·09
		O_4 .	...	23·57± ·15	...	64	...	2·07± ·07
		O_5 .	...	22·99± ·10	...	49	...	1·31± ·05
		N_1 .	...	23·31± ·17	...	42	...	1·30± ·06
	C 19-26	M .	...	27·76± ·16	...	79	...	4·05± ·07
		A_3 .	...	26·77± ·29	...	77	...	3·77± ·12
		A_4 .	...	26·73± ·29	...	70	...	3·38± ·12
		S_1 .	...	26·35± ·18	...	74	...	3·54± ·08
		S_2 .	...	25·04± ·26	...	69	...	2·92± ·14
		S_3 .	...	25·87± ·34	...	71	...	3·18± ·12
		S_4 .	...	25·86± ·18	...	68	...	2·99± ·08
		O_1 .	...	24·46± ·18	...	66	...	2·73± ·08
		O_2 .	...	23·47± ·19	...	57	...	1·97± ·09
		O_3 .	...	23·92± ·18	...	59	...	2·10± ·08
		O_4 .	...	23·47± ·18	...	52	...	1·64± ·07
		O_5 .	...	22·62± ·22	...	35	...	1·07± ·07

CORRELATION

Correlations were worked out for the number of tillers (including main stems) and yield of grain per plant. The results, which are shown in Table III, show high positive correlations in all cases between the number of tillers per plant and yield of grain, particularly in the case of wide spacing.

TABLE III

Correlation between the number of tillers and yield of grain per plant

Strain No.	Spacing	Coefficient of correlation	Remarks
A 16-34	Close . .	+0·7752±0·02801	High
C 19-26	Do. . .	+0·6243±0·0427	Do.
C 15-10	Do. . .	+0·7147±0·0338	Do.
A 16-34	Wide . .	+0·9097±0·0515	Very high
C 19-26	Do. . .	+0·8658±0·0171	Do.
C 15-10	Do. . .	+0·8823±0·0154	Do.

EAR DEVELOPMENT

In the second year of the experiment the development of the ear was studied. The formation of ear primordia in main stems was first observed on the 4th October in A16-34 and on the 12th October in C19-26, which is about 20 and 25 days, respectively, before flowering. In C15-10, ear primordia were not formed till the 20th October, which is about 35 days before flowering, indicating that the formation of ear primordia is not only later in this late pure line, but also that full development of the ear takes a longer time than in earlier-maturing pure lines. When the ear primordia were less than 2 mm. in length, the spikelets with anthers could be seen under the microscope. In Table IV are shown data recorded weekly regarding rates of growth of the ear, together with data regarding the lengths of the panicles and the heights of the plants, the data being obtained by dissecting plants not required in the main experiment.

TABLE IV

Rate of growth of ears and of the rice plant after the formation of ear primordia

	Date of observation (1934)					
A 16-34	4 October	11 October	18 October	25 October	1 November	
Ear in cm.	0·25	3·40	26·20	27·48	27·52	No increase after 1-11-34
Peduncle	..	0·16	3·22	46·20	47·84	Do.
Stem height	Failed to record	14·40	25·50	128·76	131·80	
C 15-10	18 October	25 October	1 November	8 November	15 November	22* November
Ear in cm.	0·13	0·55	7·36	22·84	26·98	27·08
Peduncle	..	..	0·32	0·42	14·60	36·46
Stem height	12·60	18·18	30·50	49·46	84·66	112·44
C 19-26	12 October	19 October	26 October	2 November	9* November	
Ear in cm.	0·37	1·86	21·78	30·40	30·50	
Peduncle	..	0·07	0·62	8·54	25·04	
Stem height	16·38	26·67	60·32	96·98	156·86	

* Flowering date

In the first week after the formation of the ears little increase in their length was observed, but after that period growth was rapid and almost at its maximum about a week before flowering in all strains under observation. No increase in length took place after flowering. The peduncles in the early stages made very slow growth, but they increased rapidly in length as soon as the ears had attained their maximum growth. It was observed during the growth of the ears that the internodes on the stems elongated. Greater elongation took place in the upper than in the lower internodes and this, together with the elongation of the peduncle, added greatly to the height of the plants after flowering.

The time that elapsed between the first appearance and the full emergence of the ear was about three days in A16-34 and C19-26 and about five days in C15-10. Thus, the rice plant in the early stages of growth appears to utilize its energy mainly in the production of leaves and tillers and later in increasing its height after ears have been fully formed.

SUMMARY

The observations made in the course of the experiments indicate that there is not a definite critical period for tillering in rice under Lower Burma conditions. Nevertheless the period of maximum tiller production in normal planting (close spacing) is up to 30-40 days after transplanting, while in wide planting the period is extended by about a month. Early production of tillers was associated with a large final number of tillers per plant, but was not associated with the date of maturity as the latest maturing pure line, C15-10, produced tillers earlier and also at a higher rate than the other two pure lines in both spacings. It is, therefore, indicated that varietal differences play an important rôle in tillering and as a high positive correlation was found between yield and the final number of ear-bearing tillers (including main stems) which in turn is associated with the early and rapid formation of tillers, it appears that the early and rapid formation of tillers may be an index of high yield capacity in rice.

The conclusions differ somewhat from those arrived at by Ramiah and Narasimham [1936] for Madras, where it was found that there was a definite critical period of tillering which was stated to be two or three weeks before the maximum tillering phase was attained. The maximum tillering phase for Madras appeared to be from three to five weeks after planting according to the duration of the variety, and thereafter there was a reduction in tiller number, due to the death of late or poorly developed tillers.

These differences may be due to differences in soil and climatic conditions, particularly the water supply throughout the growing season.

REFERENCES

Engledow, F. L. and Wadham, S. M. (1923). *J. agric. Sci.* **13**

——————— (1924). *J. agric. Sci.* **14**

Joshi, K. V. and Gadkari, M. V. (1923). *Dept. Agric. Bombay, Bulletin No.* **114**

Engledow, F. L. (1926). *J. agric. Sci.* **16**

Bhide, B. K. and Bhalerao, S. G. (1927). *Mem. Dept. Agric. India (Bot. Ser.)*, **14**, No. 7

Engledow, F. L. (1928). *J. agric. Sci.* **18**

Engledow, F. L. and Ramiah, K. (1930). *J. agric. Sci.* **20.**

Grant, J. W. (1934). *Report of Rice Research Officer, Department of Agriculture, Burma, for the year 1932-33 and 1933-34*

Ramiah, K. and Narasimham (1936). *Madras agric. J.* **24**, No. 2

Rao, B. V. N. (1937). *Indian J. agric. Sci.* **7**, 733

IMPROVEMENT OF *TORIA* (*BRASSICA NAPUS* L. VAR. *DICHOTOMA* PRAIN) AND *TARAMIRA* (*ERUCA SATIVA* L.) BY GROUP-BREEDING

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(With Plates XXXIII and XXXIV)

AMONG the various oilseed crops grown in the Punjab, *toria* and *taramira* together occupy nearly 45 per cent of the total area under all the oilseeds. Of these two crops, *toria* is pre-eminently an irrigated crop, grown almost exclusively in the canal colonies of the province, where it occupies an important place in the farm economy due to the fact that its produce is available for sale to the farmer at a time when he badly needs money for paying off land revenue. *Taramira*, on the other hand, is a crop of the drier districts of the province, and is cultivated exclusively as a *barani* (rain-fed) crop in areas which are poorly commanded by irrigation water.

Breeding investigations carried out by Singh [1928], Ali Mohammad, Singh and Alam [1930] in *toria*, and by Alam [1936] in *taramira* have shown that the plants belonging to these two crops are highly self-sterile in nature, setting very few pods and seeds under bag in spite of the facts that the various parts of their flowers are fully formed, their spores are fully functional, and their stigmas and anthers ripen at the same time.

Studies made by Ali Mohammad [1935] on the anthesis and mode of pollination in *toria* have revealed that the plants of this crop depend entirely on insects for the pollination of their flowers, and that the most ardent pollinating agents in this crop are *Andrena ilerda*, *Apis florea* and *Halictus* sp. in the order given. The same species of insects that visit *toria* flowers have been found to visit *taramira* flowers also, with the only difference that in place of *Andrena ilerda*, which is found in largest numbers in *toria* fields, *Apis florea* is the chief pollinating agent in *taramira*.

From a series of self- and cross-fertilization experiments on *toria*, Ali Mohammad [1935] concludes that the plants raised from seeds obtained by crossing attain greater height, produce more branches and form greater number of pods than those raised from seeds obtained by selfing. Alam [1936] arrives at similar conclusions in *taramira*. It is, therefore, apparent that pure-line breeding is not possible in practice for the improvement of these self-sterile crops, and resort has, therefore, to be made to certain methods of group-breeding by which crossing between plants is encouraged, but is restricted to most desirable individuals only. To attain this, the following lines of attack suggest themselves :—

(1) A restricted form of mass-selection, in which the undesirable forms are removed before pollination.

(2) Continuous inbreeding of artificially self-fertilized lines for several generations to eliminate any undesirable characters, which, due to their recessiveness, generally remain masked in an open pollinated crop, and then crossing the best of these in order to regain the vegetative vigour.

(3) Inter-crossing two or more selected plants and their selected progeny under controlled conditions for several generations until the resulting plants are fairly uniform in respect of certain desirable characters.

The efficacy of each of these methods in effecting improvement in the self-sterile crops concerned is being investigated at Lyallpur for the last four years under a scheme sanctioned by the Imperial Council of Agricultural Research for breeding investigations on *Brassica* crops. Their relative efficiency will be correctly known only after the strains produced by these methods have been extensively tested for yield, but on the face of it the last-named method, namely inter-crossing two or more selected plants and their selected progenies under controlled conditions for a number of generations, seems to offer the greatest hope of success. This method, however, involves a large number of plants to be inter-crossed each year and if this is done by hand, the work not only becomes tedious and laborious but also cannot be taken up on an extensive scale so as to make available sufficient quantity of seed, especially during the later stages of the experiment when comparative family trials and other tests have to be carried out. These considerations, therefore, led to the idea of harnessing bees under insect-proof cages for purposes of inter-crossing desirable plants, and in the present paper are outlined various experiments conducted for working out the best technique for doing so and the chief results obtained in them during the past three years.

REVIEW OF LITERATURE

Though a reference to the literature has not revealed any past record of an attempt having been made by any worker in harnessing bees or any other type of insect for crossing plants of *toria* or *taramira* crops under controlled conditions, there is some evidence available in regard to the utilization of this method for the breeding of other self-sterile crops. Waldron [1908, 1910], Gmelin [1914], Westgate and Coe [1915],Roemer [1916], Pammel and Keynoyer [1917], and Schlecht [1921] have demonstrated that red clover can be cross-pollinated by humble bees and in some cases by honey bees under cages. The experiments made by these workers were undertaken mainly with the object of investigating the pollinating efficiency of humble and honey bees, but the usefulness or otherwise of the bees for controlled pollination for breeding purposes was apparently not studied. No precautions were taken to ensure that the bees were absolutely free from red clover pollen, although an attempt was made by Gmelin and Schlecht to minimize the risk of contamination from this course by using bees taken from flowers other than those of red clover. The first attempt to employ humble bees for critical breeding work with red clover was made by Lindhard [1911, 1921], who usually placed a while family of bees under a cage made of cheese cloth containing the plants intended for crossing. To ensure that the bees were free from red clover pollen, they were placed for a short time under a cage containing *Lotus corniculatus*, before they were allowed access to the clover cage. Williams [1925] also achieved considerable success by introducing clean humble bees into cages made of wire but roofed over with glass, under which the plants of red clover to be crossed were grown. His method of cleaning the bees consisted of washing them thoroughly with water, before they were let loose in the experimental cage.

EXPERIMENTAL METHODS AND RESULTS

(*A*) *Type of bees employed*

From the very start of these experiments attention was focussed on procuring a type of bee that had a colony-forming habit so that the tedious and laborious process of catching individual insects from the open field, as practised by Williams [1925] at Aberystwyth could be dispensed with. For this reason, the most ardent pollinator of *toria* under natural conditions, namely *Andrena ilerda*, which has a solitary habit and does not lend itself to domestication, had to be totally ignored. As certain species of bees belonging to the genus *Apis* are known for their colony-forming habits, and since some of these had been proved to be next best pollinators of *toria*, attempts were made to choose a suitable type of bees from amongst them for these experiments. Of the three important species of *Apis* occurring in the Punjab, namely *Apis dorsata*, *A. florea* and *A. indica*, colony-forming habits of which have been studied by Rahman and Singh [1940], *Apis dorsata* and *A. florea* were considered unsuitable for keeping in modern hives, because the former, besides having a ferocious and vicious temperament, is prone to migrate, while the latter does not live in captivity. These two species, therefore, had to be left out of consideration and the choice ultimately fell on *Apis indica* bees, which were exclusively used for these experiments. This species of bees has a good temperament, is easy to handle, and responds to manipulation very well. Being a good gatherer of honey, it is being bred artificially at the Government Bee Farm, Nagrota and Katrain (Punjab), from which places colonies of this bee were obtained for the present study through the courtesy of Dr Khan A. Rahman, the Entomologist at the Punjab Agricultural College and Research Institute, Lyallpur.

During the first year of the experiment a number of bees separated from a colony of *Apis indica* bees were let loose in cages (described later on) under which *toria* plants to be crossed had been grown, but it was observed that the bees did not settle down and visit flowers but kept flying about near the top of the cage in an attempt to effect escape. Most of them died within one or two days after their confinement, without fulfilling the purpose for which they were meant. The method of harnessing individual bees, as practised by Williams [1925], therefore, did not prove successful at Lyallpur, and for surmounting this difficulty resort had to be made to actually rearing bees inside the cages. In all subsequent experiments, whole colonies of bees reared in Langstroth hives of the pattern shown in Plate XXXIII, figs. 1 and 2 were placed inside the experimental cages, and this method proved very successful. With their home inside the cages the bees soon got used to captivity and began visiting flowers freely in search of nectar, thus bringing about cross-pollination between plants. Since the number of plants growing under a cage was too small to provide enough nectar for the whole colony, it was necessary to replenish the food of the bees with sugar syrup twice a week. By doing so the colony maintained its strength fully throughout the flowering season of the crop and the bees continued working normally, their activity resulting in a high percentage of pod setting, as is evident from the results presented later on.

(*B*) *Trial of cages*

During the first year of the experiment, viz. 1937-38, wooden cages of two kinds, one covered over on all four sides as well as roofed over with wire-gauze having 100 meshes to an inch and the other made of fine voile cloth, were tested with a view to comparing their suitability for protecting *toria* plants and for confining bees used in crossing them. The size of these cages was 10 ft. × 10 ft. × 6 ft. A cage made of voile cloth is shown in Plate XXXIII, fig. 3. The cages were kept in position over the *toria* plants soon after they started blooming. The hives containing the colonies of *Apis indica* bees were also introduced into the cages at that time, one hive being used for each cage. In order to make the cages perfectly insect proof, meticulous care was taken to close all chinks and crevices in between the joints, and also the lower edges of the cages were pitched one to two inches deep into the soil and then banked up on all sides thoroughly with earth. Two cages of each of these types were employed—one cage in each set being used for the introduction of bees and the other kept as control. At harvest time of the crop, data were collected on the height of plants, average number of branches per plant, percentage of pod setting, average number of seeds formed per pod, etc. The comparative data for the experimental as well as control cages (Table I) show that although equally good setting of pods was obtained with the help of bees both in the voile and wire-gauze cages, yet the latter is considered less satisfactory for crossing *toria* plants under controlled conditions, firstly because the wire gauze could not resist the heat of the day and cracked in a very short time, and secondly it could not check, the passage of tiny insects like thrips, etc. through its meshes, which may be a serious source of foreign pollen contamination. On account of these defects, and also because of its prohibitive initial cost, the wire-gauze cage had to be rejected, and during subsequent years only voile-cloth cages were employed for these experiments. The voile cloth is not only completely insect-proof, but also permits more air and light inside the cage than wire gauze, thus helping the plants to attain normal stature without making them much drawn out. The initial cost of voile-cloth cages is also much lower than that of wire-gauze cages, and since such cages do not lack in efficiency in any way, they could be usefully employed by all workers intending to inter-cross plants under controlled conditions with the help of bees.

TABLE I

Growth and fruiting record of toria *plants grown under cages of different types in 1937-38*

Type of cage used and the treatment given	Total number of plants under observation	Average height of plants in inches	Average number of branches per plant	Average No. of		Percentage of pod setting	Average number of seeds per pod
				Flowers borne per plant	Pods formed per plant		
Voile-cloth cage with bees introduced	20	55·0	6·7	509·4	302·6	59·3	18·7
Voile-cloth cage (control)	20	63·0	6·3	427·0	73·4	16·1	5·4
Wire-gauze cage with bees introduced	20	50·2	5·0	164·7	110·2	66·9	11·3
Wire-gauze cage (control)	20	55·0	5·9	344·4	42·2	12·2	3·7

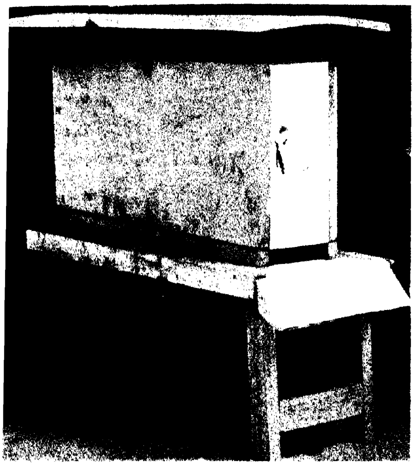

FIG. 1. A Langstroth bee-hive in which *Apis indica* bees were bred

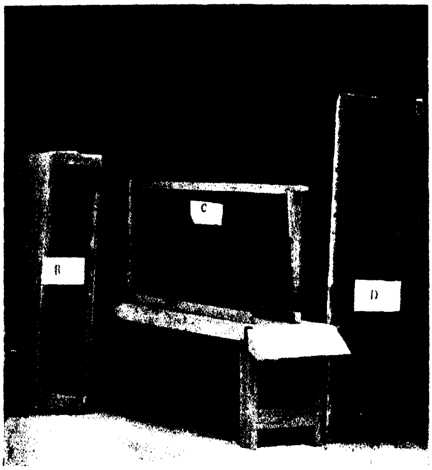

FIG. 2. The component parts of the bee-hive separately

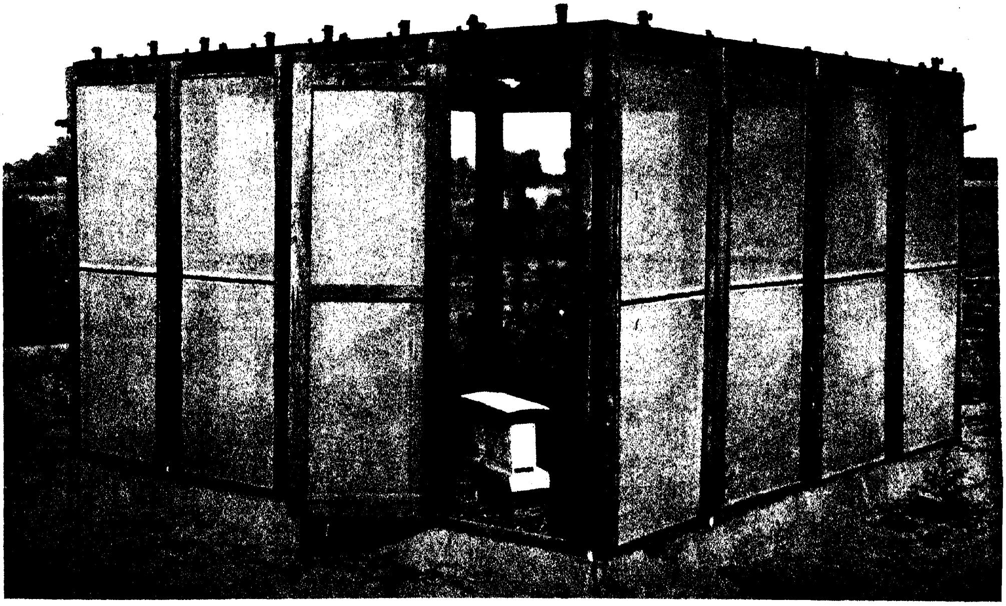

FIG. 3. An insect-proof cage made of voile cloth, under which hive-bred *Apis indica* bees were harnessed for crossing plants of *toria* and *taramira*

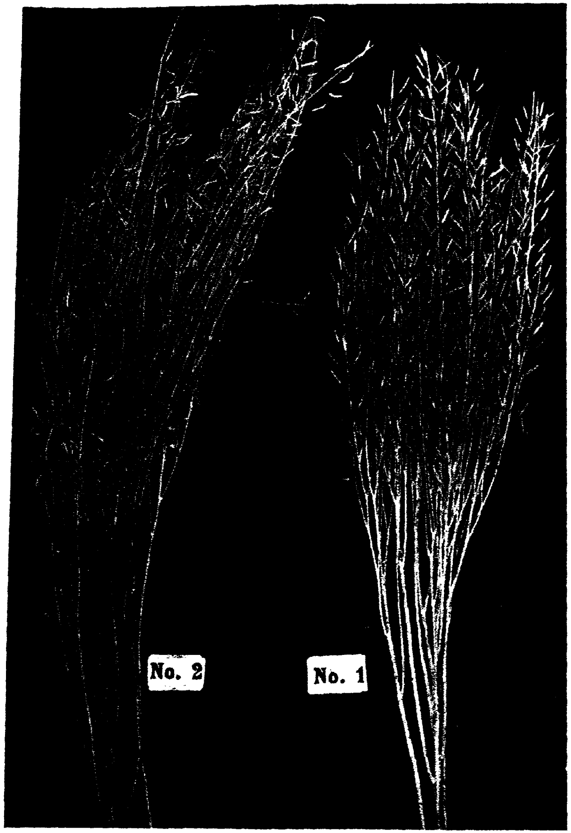

FIG. 1. No. 1. A *toria* plant from the cage to which *Apis indica* bees had been introduced

No. 2. A *toria* plant from the control cage

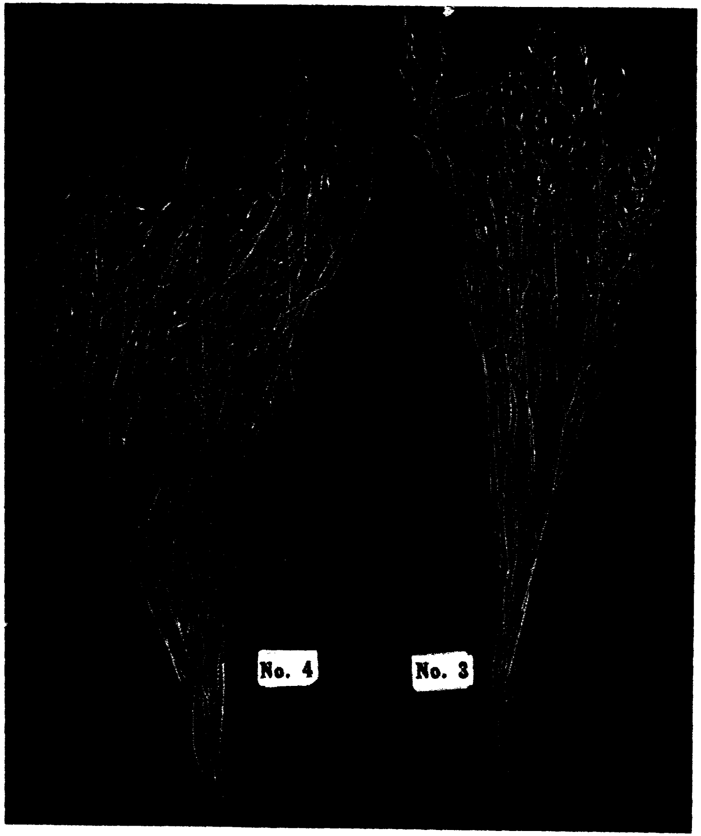

FIG. 2. No. 3. A *taramira* plant from the cage to which *Apis indica* bees had been introduced

No. 4. A *taramira* plant from the control cage

(*C*) *Pod-setting in* toria *and* taramira *with and without the help of bees*

In two subsequent years, viz. 1938-39 and 1939-40, experiments with hive-bred *Apis indica* bees were continued with a view to comparing the pod setting in *toria* and *taramira* plants grown under voile-cloth cages referred to above, to one of which bees were introduced and the other was kept control. Plate XXXIV shows the photographs of *toria* and *taramira* plants taken from both these cages. It is apparent that the plants of both these crops grown under the control cage, to which no bees had been introduced, formed but few pods containing a very few seeds, while the plants grown under the cage containing bees were fully loaded with normal, healthy pods. The actual figures of plant height, number of branches per plant, pod setting percentage, etc. were recorded during two years' experiments on *toria* and one year's experiment on *taramira* and it is apparent from the data presented (Table II) that not only was the pod setting on the plants of both *toria* and *taramira* grown under cages to which artificially bred *Apis indica* bees had been introduced several times higher than that occurring on plants grown under the control cages, but also the pods and seeds formed with the help of bees were much better developed than those obtained in the case of control cages. It may also be stated that the pod and seed setting obtained under controlled conditions with the help of bees used in these experiments compare very favourably with that occurring under natural conditions, in which case, the percentage of pod setting was found to vary between 60 and 85, and the number of normal seeds per pod ranged between 10 and 20. On this account the method of harnessing hive-bred *Apis indica* bees for crossing selected plants and their selected progeny under controlled conditions can be used effectively for the improvement of self-sterile oleiferous Brassica crops concerned.

TABLE II

Growth and fruiting record of toria *and* taramira *plants grown under voile-cloth cages*

(1938-39, 1939-40)

Year	Name of crop and the number of strain	Treatment	Number of plants under observation	Average height of plants in inches	Average number of branches per plant	Average No. of		Percentage pod setting	Average number of seeds per pod
						Flowers borne per plant	Pods formed per plant		
1938-39	*Toria* strain P 130	Control (No bees)	15	49·6	9·86	383·39	83·46	21·76	9·49
	Do. .	Bee-hive placed in the cage	20	56·15	11·8	751·55	573·20	76·26	13·29
1939-40	Do. .	Control (No bees)	25	...	...	406·1	89·0	21·9	8·56
	Do. .	Bee-hive placed in the cage	25	58·8	6·28	189·3	148·1	78·2	15·98
	Toria strain P 150	Control (No bees)	25	...	...	571·2	95·1	16·6	7·45
	Do. .	Bee-hive placed in the cage	25	56·8	6·44	218·7	184·1	84·2	13·37
	Taramira strain P 2	Control (No bees)	25	48·6	7·3	158·1	27·1	17·1	5·23
	Do. .	Bee-hives placed in the cage	25	46·2	6·04	115·0	72·8	63·2	18·62

(*D*) *Freeing the bees of foreign pollen*

For attaining full success in the method of group-breeding described above, it is important that the bees should be completely freed of all foreign pollen before they are introduced to the experimental cages. Williams' method of washing the bees in water and drying them in the sun before letting them in the cages cannot work satisfactorily in the method of group-breeding described here, as in this method whole colonies of bees are required to be introduced to the cages instead of individual bees. Ali Mohammad [1935] has found that the pollen of *toria* remains viable for about seven days after liberation from the anthers. This fact could be made use of in freeing the bees of all foreign pollen sticking to their bodies, the method suggested being captivating the bees in their hives for about a week before they are required to be introduced to the experimental cages. By feeding the bees, during this period of captivity, with sugar syrup their colony strength could be fully maintained. In the case of *taramira* also the period of viability of the pollen is about a week, and the method of shutting up the bees in the hives for that period should prove quite efficacious in this crop also for getting rid of all foreign pollen adhering to the body of the bees.

(*E*) *Utilization of hive-bred bees for increasing yield of* toria

As already mentioned earlier in this paper, seed production in *toria* depends largely on the pollinating activities of three species of insects. It is, therefore, a matter of great concern to the cultivators of this crop to know whether the insects responsible for bringing about cross-pollination are sufficiently numerous in fields to deal effectively with all *toria* crops grown for seeds. Ali Mohammad, Singh and Alam [1930] have found that in certain years the yields of *toria* crop are reduced considerably, owing to insufficiency of insect visitors. Thus, any means adopted for increasing the number of pollinating insects would be of direct benefit and should result in increased yields of this crop.

Several workers have suggested different methods for circumventing the scarcity of insect pollinators in various crops. In fruit trees, Hendrickson [1916], Overholser [1927] and Farrar [1931] suggest supplementing of wild insect pollinators by means of hive bees. In red clover, Fryer and Stenton [quoted by Williams, 1925] advocate that the number of humble bees in any particular locality may be increased by providing the queens with suitable nesting sites and hibernating quarters. Williams [1925] suggests the method of eradicating the natural enemies of *Bombi*, such as mice, shrews and voles, for increasing their number under natural conditions. He also thinks that the number of bees on the clover crop could be increased if plants which are visited by the clover pollinators were cut back when the clover is in flower.

With a view to finding out the scope of utilizing hive-bred *Apis indica* bees for obtaining increased yields of *toria* crop under field conditions, experiments were started in the Oilseeds Breeding Section, Lyallpur, during the year 1938-39. For the purpose of these experiments two large bee-hives of *Apis indica* were placed in a *toria* field of about two acres in area, and the frequency of insect visits per plant in the year 1938-39 and per inflorescence in 1939-40 and percentage of pod setting obtained from this field were compared with those obtained from a normal field of *toria* crop selected at a distance of four miles from the aforesaid field so as to reduce to minimum the chances of the bred bees reaching that field. Observations on insect visits were made over a period of 15 days during the main flowering season of the crop, and the data on pod setting were recorded for 100 plants selected at random in each field.

It is apparent from the data presented (Table III) that the number of insect visitors per inflorescence as well as per plant per day was roughly three times more in the field where bee-hives had been placed as compared to the normal field in which no bee-hives had been placed. The results also show that with an increase in the frequency of insect visits there was a significant increase of 15·67 per cent and 8·08 per cent in the pod setting during the years 1938-39 and 1939-40, respectively. Since the strain of *toria* grown in the fields under experiment was the same, it is safe to conclude that the increased pod setting in the field where bee-hives had been placed must be the result of increase in the insect population of that field which, as is to be expected, would make the pollination of a larger number of flowers possible than would be the case under conditions where the number of insect pollinator is below the full needs of the crop. The rearing of bees alongside the fields of *toria*, therefore, appears to be a good method of increasing the frequency of insect visitors in the field, which is likely to result in better setting of pods and consequent higher yields of the produce concerned.

TABLE III

Effect of additional bees bred in toria *crop on the number of visits of insect pollinators and pod setting per plant*

(1938-39, 1939-40)

Year	Treatment	Average No. of visits of insect pollinators per plant per day	No. of insect visits expressed as percentage of control	Percentage pod setting	Mean difference of pod setting	Critical difference of pod setting at 1 per cent level	Difference significant or not
1938-39	Two bee-hives placed in the field	161·2	351·7	79·66	+15·67	4·37	Significant
	No bee-hives placed in the field	4·83	100·0	63·99	...	...	...
1939-40	Two bee-hives placed in the field	46·55*	307·06	73·13	+8·08	4·58	Significant
	No bee-hives placed in the field	15·16*	100·0	65·05	...	...	...

*These figures represent visits per inflorescence.

SUMMARY

The details of a new method of group-breeding, in which *Apis indica* bees could be harnessed under insect-proof cages for crossing selected plants of *toria* (*Brassica napus* L. var. *dichotoma*, Prain) and *taramira* (*Eruca sativa* L.) with a view to improving them is described.

Of the two types of cages experimented with, the best results were obtained by using cages made of very fine voile cloth. Wire-gauze cages proved unsuitable for the purpose, on account of their shorter life, high initial cost, and inability to check the passage of thrips, etc. which may be a serious source of foreign pollen contamination.

Introduction of individual *Apis indica* bees to the cages did not prove successful in effectively crossing the *toria* and *taramira* plants. However, by actually rearing colonies of bees inside the cages in Langstroth hives the bees worked normally, their activity resulting in as good pod and seed setting as is obtained under open field conditions.

As for the method of freeing bees of foreign pollen before they are introduced to the experimental cages, it is suggested that the bees should be kept in captivity inside their hives for about a week, so that all pollen sticking to their bodies loses its viability and is thus disabled to viciate the choice plants intended to be inter-crossed with the help of bees.

Data are also presented to show that the insects responsible for bringing about cross-pollination in *toria* under natural conditions are below the full needs of the crop, and that the pod setting and consequently the yield of this crop could be considerably enhanced by supplementing the insect population of *toria* fields with hive-bred *Apis indica* bees.

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REFERENCES

Alam, Z. (1936). *J. Genet.* **32**, 257-76

Ali Mohammad (1935). *Indian J. agric. Sci.* **5**, 1-30

Ali Mohammad, Singh, R. D. and Alam, Z. (1930). *Indian J. agric. Sci.* **1**, 109-36

Farrar, C. L. (1931). *J. Econ. Ent.* **14**

Gmelin, H. M. (1914). *Mededeelingen van de Ryko Hoogere Land-Fuin en Bosch.*, **Deel 7**, *Afl.* 5

Hendrickson, A. H. (1916). *Bull. Calif. Agric. Expt. Sta.* No. **274**

Lindhard, E. (1911). *Tidsskr. f. Planteavl.* Bd. **18**

——— (1921). *Zeitschr. f. Pflanzen* **8**, *Heft* 2

Overholser, E. L. (1927). *Bull. Calif. Agric. Expt. Sta.* **426**, 1-17

Pammel, L. H., and Keynoyer, L. A. (1917). *Proc. Iowa Acad. Sci.* **18**

Rahman, K. A. and Singh, S. (1940). *Bull. Dept. Agric. Punjab*

Rocmer, T. (1916). *Zeitschr. f. Pflanzeni* Bd. **4**, *Heft* 3

Singh, R. D. (1928). *Ann. Rept. Dept. Agric. Punjab*, 1928-29

Schlecht, F. (1921). *Zeitschr. f. Pflanzen.* Bd. **8**, *Heft* 2

Waldron, L. R. (1908). *North Dak. Agric. Expt. Sta. Dickenson Sub-Expt. Sta., 1st Ann. Rept.*

——— (1910). *North Dak. Agric. Expt. Sta. Dickenson Sub-Expt. Sta., 3rd Ann. Rept.*

Westgate, J. M. and Coe, H. S. (1915). *Bull. U. S. Dept. Agric.* **289**

Williams, R. D. (1925). *Bull. Welsh Plt. Breed. Sta., Ser.* H, No. **4**

SOOTY-BLOTCH AND FLY-SPECK OF APPLE FRUIT IN KUMAUN

BY

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THE sooty-blotch and fly-speck disease is caused by *Leptothyrium pomi* (Mont. and Fr.) Sacc. and appears commonly on light-coloured and late varieties of apple, such as Claygate Pearmain, Hawthorn Greening, Rymer, Jonathan, Delicious and Newton Pippin. A strain of the same fungus infects pear fruits. It is known to occur in England, Canada, the United States of America, New Zealand, and Australia, in fact in all apple-growing countries. Macoun [1907] reported this disease from Canada. In England it was first recorded by Salmon [1910]. In India it was recognized first at Ramgarh, Kumaun [Butler, 1918] and again in the same locality [Butler, 1920]. In Chaubattia it was first recorded by the author in 1934.

The normal growth of the fruits affected with the disease is not checked. But they become badly blemished and thus their market value is reduced. The diseased fruits fetch only half the price of clean fruits.

The disease is known as sooty-blotch and fly-speck. The blotches are irregular in outline to roughly circular. At first the colour is pale brown, but later on it becomes sooty brown or black. Single spots measure $\frac{1}{4}$-$\frac{1}{2}$ in. in diameter ; often several lesions coalesce, covering the apple as if with soot. Spots become radiating or star-like, composed of a thin felt of dark brown interwoven threads which are seen with the naked eye or better with a hand lens. Fly-speck is simply a different symptom of the disease. The two are found in the same situation and under similar conditions except that fly-speck develops later than sooty-blotch. In fly-speck a number of small shiny dots appear on the surface of the apple, the specks closely resembling those made by a fly. Both sooty-blotch and fly-speck are superficial and are hardly skin deep.

The sooty-blotch spots are composed of the fungus *Leptothyrium pomi* (Mont. and Fr.) Sacc. The black dots of fly-speck are the sclerotial bodies of the fungus, which presumably enable it to overwinter. In late spring each sclerotial body undergoes certain developmental changes and forms a pycnidium. Conidia develop within the pycnidia and start fresh infections in summer. Apparently infection does not occur before July. Pieces of the mycelium of the fungus which form the blotches become swollen and break off, are carried by water or otherwise to other fruits, and start fresh infections. The disease increases on fruits in storage.

CONTROL MEASURES

Three methods of control, namely by spraying, by thinning the fruit and by washing fruits with chemicals, were carried out.

Spraying

Butler [1918] carried out spraying experiments in Kumaun orchards and found that trees sprayed with lime-sulphur showed less disease than unsprayed ones. To control the damage, a spraying expriment with home-made lime-sulphur wash and Avon's colloidal sulphur was started in 1938. The experiment was on the lines of work done in U. S. A., described by Hesler and Whetzel [1924]. The prepared concentrated lime-sulphur tested 32° Baume, specific gravity 1·283; and each gallon of this concentrated solution was diluted by adding 40 gallons of water. The lime-sulphur was prepared in the usual manner as given by Butler [1918]. Avon's colloidal sulphur was prepared by mixing 5 lb. of the concentrated commercial preparation with 100 gallons of water. Twenty-one trees of apple of each of two varieties, viz. Claygate Pearmain and Esopus Spitzenberg of the same size and age were selected in two separate blocks of the orchard, named N and E respectively. Each block was divided into seven sub-blocks, each sub-block having three trees, two for the treatments and one as control. The two treatments together with controls were randomized in each sub-block.

In one block (block E) the spraying was done on the following dates :—

28 March 1938 (open cluster stage)
11 April 1938 (petal fall stage)
19 April 1938 (fruit formation)
2 August 1938 (when the fruits were mature)

In the second block (block N) they were done a day later each time. In the third week of August 1938 when the fruits were ready for picking a record of the infected and uninfected fruits was taken for each individual tree under experimentation.

The analysis of variance was worked out and is given in Tables I and II. It is concluded that in block N the treatment A=B, B=C and A>C, while in block E the treatment A>B>C.

The cost of spraying per tree comes to about 12 annas and is certainly too much for an orchardist to spend, and therefore this method of controlling the disease does not seem to be feasible.

TABLE I

Comparison of different treatments in block E

No.		Mean percentage of good fruits			General mean	Standard error of difference	Critical differences for significance	Whether significant by '*z*' test
		A Lime-sulphur	B Avon's colloidal sulphur	C Unsprayed (control)				
1	Per treatment	58·28	19·22	0·45	25·98	8·04	17·51916	Yes, $P = 0{\cdot}01$
2	Percentage on general mean	224·32	73·97	173·97				
3	Percentage on control	129·51	4271·11	100·00				

TABLE II

Comparison of different treatments in block N

No.		Mean percentage of good fruits			General mean	Standard error of difference	Critical difference for significance	Whether significant by 'z' test
		A Lime-sulphur	B Avon's colloidal sulphur	C Unsprayed (control)				
1	**Per treatment** .	9·88	5·64	0·70				
2	**Percentage on general mean**	182·96	104·44	12·96	5·40	2·87	6·39436	Yes, *P*=0·01
3	**Percentage on control**	1268·57	805·71	100·00				

Thinning the fruit

Thinning is known to help in the production of a better class of fruits, both as regards their size and colour. Fruits from thinned trees fetch a better price in the market. There is also not much difference in gross weight of fruits obtained from thinned and unthinned trees. The experiments carried out at Chaubattia by the Horticulturist fully substantiate the above statements.

In 1938 thinning experiments were laid out by the Horticulturist at Rajkhet orchard (Bhowali). The thinning was based on the volume of the tree and the fruits retained with different treatments were according to unit volume of the tree. There were three treatments, namely (*i*) one and a half fruits retained per cubic foot of the volume of the tree, (*ii*) two fruits retained per cubic foot of the volume of the tree, and (*iii*) unthinned (control) with 3·3 fruits per cubic foot of the volume of the tree. The horticulturist carried out his experiment on Rymer (a late variety). The purpose of the experiment was to find out whether thinning has any effect in decreasing the incidence of the disease. The fruits harvested from each treatment were graded according to their size in five grades with diameter of (*a*) 3¼ in. and above, (*b*) between 3 in. and 3⅛ in., (*c*) between 2⅞ in. and 2¾ in. and (*d*) 2⅝ in. and below. After this, fruits of each size grade were further graded into four groups, depending on the percentage infection of the sooty-blotch and fly-speck under each size grade, viz. (*a*) between 50 and 70 per cent, (*b*) between 30 and 50 per cent, (*c*) between 10 and 30 per cent, and (*d*) below 10 per cent. From the size grading the total surface area of the fruits from each individual tree was calculated and from the infection grading of size and the size grades the total infected area of individual fruit was obtained. The percentage of the infected surface area to the total surface area formed the criterion for judging the effect of thinning on the incidence of sooty-blotch. Table III summarizes the results obtained. It shows that the most severely thinned trees (1½ fruit retained per cubic foot of the volume of the tree) had significantly less incidence of the disease than unthinned (control) having 3·3 fruits per cubic foot of the volume of the tree. The lesser degree of thinning (two fruits retained per cubic foot of the volume of the tree) did not show any significant difference from either the unthinned (control) or the most severely thinned (1½ fruit retained per cubic foot of the volume of the tree). Thus it appears that the incidence of sooty-blotch disease is minimum only under conditions of severest thinning, namely 1½ fruit retained per cubic foot of the volume of the tree.

Table III

Effect of thinning of apple fruits on percentage of infection of sooty-blotch

No.		Mean percentage infection			General mean	Standard error of difference	Critical difference for significance	Whether significant by 'z' test
		One and a half fruits per cubic foot of the volume of the tree	Two fruits per cubic foot of the volume of the tree	Unthinned (control) 3·3 fruits per cubic foot of the volume of the tree				
1	Per treatment	11·9	13·9	15·3	13·7	1·37	3·05	Yes, $P = 0·05$
2	Percentage on general mean	87·00	101·5	111·7				
3	Percentage on control	77·8	90·8	100				

Chemical treatment

Washing the apple fruits with bleaching powder 5 per cent was recommended by Bottomley [1935] and Wormald [1936]. Forty-eight apple fruits of one variety (Sturmer Pippin) of the same maturity, which were already affected with sooty-blotch and fly-speck, were used. The infected area of the fruits was about 20 per cent. These were divided into six lots of eight fruits each.

Six treatments each replicated eight times were carried out : (1) control (untreated) ; (2) fruits washed with tap water, the sooty-blotch removed and dried with a cloth ; (3) fruits dipped in bleaching powder solution (5 per cent) for one minute, exposed to the air for ten minutes, washed with tap water, sooty-blotch removed and dried with a cloth ; (4) fruits dipped in a solution of sodium chlorate (1 per cent) for one minute, exposed to air for ten minutes, washed with tap water to remove the sooty-blotch, and dried with a cloth ; (5) fruits dipped in 2 per cent sodium chlorate and then proceeded with as in treatment (4) ; (6) fruits dipped in 3 per cent sodium chlorate solution and then proceeded with as in treatment (4).

The fruits of one treatment were kept in one tray and each fruit was kept apart from the other. All the six trays were placed in the fruit godown on 8 September 1939. The fruits were examined periodically up to 19 March 1940. From Table IV it will be seen that there was an increase in the intensity of both sooty-blotch and fly-speck in treatments (1) (untreated control), (2) (washed with water), (4) and (5) (treated with sodium chlorate 1 and 2 per cent respectively). The fruits treated with bleaching powder 5 per cent (treatment 3) and those treated with 3 per cent sodium chlorate (treatment 4), showed very slight increase in the intensity of either sooty-blotch or fly-speck,

TABLE IV

Observations regarding the control of sooty-blotch and fly-speck disease of apple fruits under various treatments

Fly-speck (1) below 10 numbered
(2) 10—15 +
(3) 16—20 + +
(4) 21—30 + + +
(5) beyond 30 + + + +

No.	Treatment		8-9-39	19-3-40
I	Untreated control	Average percentage of sooty-blotch	20	85
		Average incidence of fly-speck	+	+ + + +
II	Washed with water only	Average percentage of sooty-blotch	0	50
		Average incidence of fly-speck	+ +	+ + +
III	Dipped in 5 per cent bleaching powder	Average percentage of sooty-blotch	0	0
		Average incidence of fly-speck	7	+ +
IV	Dipped in 1 per cent sodium chlorate	Average percentage of sooty-blotch	0	60
		Average incidence of fly-speck	+ + +	+ + + +
V	Dipped in 2 per cent sodium chlorate	Average percentage of sooty-blotch	0	40
		Average incidence of fly-speck	+ +	+ + + +
VI	Dipped in 3 per cent sodium chlorate	Average percentage of sooty-blotch	0	0
		Average incidence of fly-speck	+ +	+ + +

DISCUSSION

Sooty-blotch and fly-speck of apples is a serious disease in Kumaun. Although it does not affect the flesh of apples, it causes disfigurement and thereby reduces the market value by nearly half. Of the three different treatments discussed in the paper, thinning of fruits and use of 5 per cent bleaching powder solution and 3 per cent sodium chlorate solution in washing the fruits are cheap and practicable. Thinning does not affect the gross yield of the crop, but reduces the incidence of the disease.

SUMMARY

1. Sooty-blotch and fly-speck of apples is caused by *Leptothyrium pomi* (Mont. and Fr.) Sacc. It causes blemishes in the fruit and reduces its market value.

2. The blotches caused by sooty-blotch are irregular in outline, tending to be circular. The colour at first is pale, but later on it becomes sooty brown or black. Single spots measure $\frac{1}{4}$-$\frac{1}{2}$ in. in diameter. They often coalesce, covering the apple. Spots exhibit a radiating structure composed of a thin felt of dark brown interwoven threads which can be seen with the naked eye or with a hand lens.

3. Fly-speck is a different symptom of the same disease. In this a number of shiny small dots appear on the surface of the apple. Both sooty-blotch and fly-speck are superficial in nature,

4. The sooty-blotch spots are composed of the hyphae of the fungus, *Leptothyrium pomi* (Mont. and Fr.) Sacc. The dots of fly-speck are sclerotial bodies of the same fungus.

5. It is not known how the fungus hibernates in winter. It has been suggested that it hibernates on the apple twigs presumably as sclerotial bodies. These sclerotial bodies, after undergoing developmental changes, give rise to pycnidia from which pycnospores are discharged in summer and cause fresh infection of fruits. At times pieces of the mycelium of the fungus get broken off and are carried by the rains or otherwise to other fruits.

6. The methods of controlling the disease consist of : (*i*) spraying, (*ii*) thinning the fruits, and (*iii*) chemical treatment of fruits intended for storage.

(*i*) *Spraying.*—By spraying the fruits with either lime-sulphur or Avon's colloidal sulphur the disease can be successfully controlled. The method is costly and tedious.

(*ii*) *Thinning the fruits.*—Thinning of the fruits (1½ fruits retained per cubic foot of the volume of the tree) appreciably decreases the incidence of the disease. There was not much difference in gross weight of fruits obtained from thinned and unthinned trees. Fruits from thinned trees were bigger in size and more coloured.

(*iii*) *Chemical treatment.*—Washing the fruits with either a 5 per cent solution of bleaching powder or a 3 per cent solution of sodium chlorate controls the disease in storage.

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REFERENCES

Butler, E. J. (1918). *Fungi and diseases in plants*, pp. 144-5 : Thacker Spink and Co., Calcutta

Butler, E. J. (1918). *Rept. Agric. Res. Inst. Pusa (1918-19)*, p. 74

———— (1920). *Rept. Agric. Res. Inst. Pusa (1919-20)*, p. 61

Bottomley, [A(Veril)M] (1935). *Fug. S. Africa X*, 106. p. 31

Hesler, L. R. and Whetzel, H. H. (1924). *Manual of fruit diseases* ; The Macmillan Company, pp. 12, 104

Macoun, W. T. (1907). *Canada Expt. Farms Rept. (1906)*, pp. 107, 123-4

Salmon, E. S. (1910, 1). *Gard. Chron.* **3**, 48, p. 443

———— (1910, 2). *South-Eastern Agric. Col. (Wye)* ; *Rept. on Econ. Mycol. (1909-10)*, pp. 29-32

Wormald, H. (1936). *Rept. East Malling Res. Sta.*, pp. 194-7

STUDIES ON THE CHEMICAL CONSTITUENTS OF INDIAN LATERITIC AND RED SOILS

II. INFLUENCES OF FREE SESQUIOXIDES AND FREE SILICA COMPONENTS OF INDIAN RED SOILS ON THE BUFFER CURVES OF THE SOILS

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IN a recent paper Raychaudhuri and Sulaiman [1940] have discussed the importance of determining the percentages of free sesquioxides and of free silica in Indian red soils on profile basis, which would indicate the manner in which the amorphous product of weathering has been washed down the soil profiles. They have determined the percentages of free sesquioxide components by following the method devised by Hardy [1931], later on modified by Hardy and Rodrigues [1939], and also by following the method devised by Drosdoff and Truog [1935]. The method of determining free sesquioxides by the latter workers, subsequently modified by Truog and co-workers [1937] appears to be specially interesting, in that it enables us to separate the amorphous products of weathering, viz. free silica, free alumina, and free iron oxides, from the crystalline products of weathering and thus to study separately the physico-chemical properties of the crystalline product of weathering which represents really the active material of the soil. It was felt desirable to compare the base-exchange properties of the residue left after treatment of the soils by the Truog's reagent for the separation of the sesquioxide components. In the work embodied in the present paper a comparison has been made of the buffer curves of some profile samples of Indian red soils and of the residues of the same soils after treatment by the Truog's reagent. Hardy [1931] has postulated that iron oxide absorbs alizarin sulphonate dye in the non-ignited state, whilst on ignition it loses its power of absorbing the dye. On the other hand, alumina gel in the non-ignited state possesses no power of absorbing alizarin sulphonte, whilst in the ignited state it acquires the power of absorbing the dye. It was felt desirable to compare, in this connection, the buffer curves of ignited and non-ignited gels of silica, alumina and iron oxide.

EXPERIMENTAL

Preparation of inorganic gels

(*a*) *Silica gel.*—It was prepared by hydrolysing pure silicon tetrachloride in a large volume of water and then adding an excess of ammonia. The gel obtained was at first dialysed in a parchment bag immersed in distilled water. It was then electrodialysed in a 220-volt current for a long time with a constant flow of distilled water until there was no trace of ammonia and chlorine in the cathode and anode chambers respectively. The presence of ammonia was tested with the help of Nessler's reagent and that of chlorine by means of a solution of silver nitrate. The electrodialysed gel was then filtered and dried in an electric oven kept at a constant temperature of 34°C. until the weight of dry gel was found constant.

(*b*) *Aluminium hydroxide gel.*—Ammonia was added in excess to a solution of pure aluminium chloride in water. The gel of aluminium hedroxide was then electrodialysed in exactly the same way as before, until ther was no trace of chlorine and ammonia. The electrodialysed gel after filtration was dried as before.

(*c*) *Ferric hydroxide gel.*—Excess of ammonia was added to a solution of pure ferric chloride in water. The jelly-like mass so obtained was electrodialysed, filtered and dried to constant weight as in the previous cases.

Electrodialysis of inorganic gels.—The gels were electrodialysed in a three-chambered electrodialysis vessel devised by Mattson [1926]. The substances were kept in the middle chamber and electrodialysis was carried out until the liquid at the cathode was neutral.

Ignition of the inorganic gels.—The ignition of the inorganic gels was carried out in a thermo-regulated electric muffle furnace at 750°C. for 15 minutes.

Determination of buffer curves.—For the determination of buffer courves the procedure devised by Schoeld [1933] was used [Raychaudhuri and Nandy-majumdar, 1940].

Sodium sulphide-oxalic acid treatment for the removal of free iron and aluminium oxides and colloidal, i.e. free silica. [Truog et al., 1937].—5 gm. of soil passing through a 100-mesh sieve were placed in a litre beaker and 25 c.c. of 10 per cent hydrogen peroxide were added. The beaker was covered, allowed to stand for about two hours, heated for several hours at a lower temperature and then at a higher temperature without the cover glass until the contents were dry. This treatment was repeated until the action ceased when hydrogen peroxide was added. 650 c.c. of water and 5 c.c. of 20 per cent sodium sulphide solution were added, the mixture was boiled for five minutes and 10 gm. of ammonium chloride were added. By means of a low flame the suspension was kept at 80°-90°C. until it was ready for centrifuging. Oxalic acid solution was added immediately in small quantities with vigorous stirring until *p*H 6 was reached using bromo-thymol blue on a spot plate. 10 c.c. of 20 per cent sodium sulphide solution were then added with stirring. Oxalic acid was then added rapidly until *p*H 7 was again reached, then slowly from *p*H 7 to *p*H 6, and then rapidly to *p*H 3·5, using bromo-phenol blue on a spot plate. After stirring and allowing to stand for a few minutes until the black sulphides had dissolved, the *p*H was again brought back to 7 with 2 *N* ammonia solution, when ferrous sulphide and ammonium sulphide were formed ; 5 c.c. of 20 per cent sodium sulphide solution were then added, and oxalic acid was added rapidly until *p*H 7 was again reached and then slowly from *p*H 7 to *p*H 6 and then more rapidly to *p*H 3·5. This treatment was repeated three to four times. The suspension was digested at 80°-90°C. until coagulation took place which was then transferred to centrifuge tubes, allowed to stand for a few minutes, the supernatant liquid was collected by decantation after centrifuging and the residue was washed twice with 0·001N hydrochloric acid containing 5 per cent sodium chloride by centrifuging. The supernatant liquid together with the washings was heated on a hot plate until the clay settled, the clear liquid was then siphoned off and the clay was washed with 0·001N hydrochloric acid containing 2 per cent sodium chloride. The supernatant liquid together with the washings was evaporated to dryness and the residue was dehydrated at 110°C. for two to three hours. The residue was treated with 25 c.c. of 6 N hydrochloric acid, digested on a hot plate for a few minutes and then diluted to about 50 c.c. The silica was filtered off and was determined in the usual way.

In order to remove sulphur from the residue, it was washed twice with 95 per cent ethyl alcohol to remove water, then three times with a mixture of one volume of carbon disulphide and 2 volumes of 95 per cent ethyl alcohol and finally four to five times with 95 per cent ethyl alcohol to remove carbon disulphide.

Determination of percentages of free alumina and free iron oxide.—The presence of free alumina and free iron oxide in soil was determined by following essentially the alizarin-adsorption method of Hardy and Rodrigues [1939].

For the determination of free alumina two portions, each of mass 1 gm., of air-dried soil passing through a 100-mesh sieve, were taken in silica crucibles covered with lids, and were ignited in a thermo-regulated electric muffle furnace at 750°C. for 15 minutes. After cooling, the ignited material was transferred to large boiling tubes, one containing 20 c.c. of 0·5 per cent solution of sodium alizarin sulphonate in boric alcohol, the other containing 20 c.c. of boric alcohol alone. Both tubes were fitted with Hopkin's reflux condensers and heated in a gently boiling water-bath for 10 minutes. After settling, the supernatant liquid in each tube was decanted into a Buchner funnel containing a pad of filter paper pulp and filtered by suction into a filtering flask. In each case the soil material in the tube was treated with 20 c.c. boric alcohol, boiled and the whole suspension was poured into the funnel and filtered by suction. Excess of dyestuff was next removed in one case by washing with several portions of boiling distilled water until the filtrate was quite colourless. The duplicate (' blank ') treatment was carried out in exactly the same manner, the material being given the same number of washings.

The adsorbed dye-stuff from the stained material was extracted by treatment with boiling saturated aqueous sodium oxalate-oxalic acid solution at pH 3·8. The paper pad and the stained material were returned to the boiling tubes, adhering particles being washed off the funnel with oxalate solution. The volume was made up to about 30 c.c., and the mixture was boiled, settled and decanted into the funnel containing a fresh filter paper pulp. The washing was repeated several times with small quantity of oxalate solution and finally the volume was brought to a definite amount for the purpose of colorimetric comparison with a standard. The concentration of the dye-stuff in the extract was measured in a Duboscq colorimetre against a standard.

Suitable alizarin standards were prepared by diluting 0·25-2 c.c. of the original 0·5 per cent solution of alizarin Red-S with appropriate volume of the ' blank ' oxalate extract of the unstained material; this corrected the colour caused by iron and organic compounds soluble in the oxalate solution.

For the determination of free iron oxide exactly the same procedure with fresh unignited soil was followed, the blank correction being applied in each case.

RESULTS AND DISCUSSION

Buffer curves of electrodialysed gels

Buffer curves of the following substances have been studied :—

(1) Ignited and non-ignited electrodialysed iron oxide gel,
(2) Ignited and non-ignited electrodialysed alumina gel, and
(3) Ignited and non-ignited electrodialysed silica gel.

The results are shown in Table I, and graphically in Fig. 1.

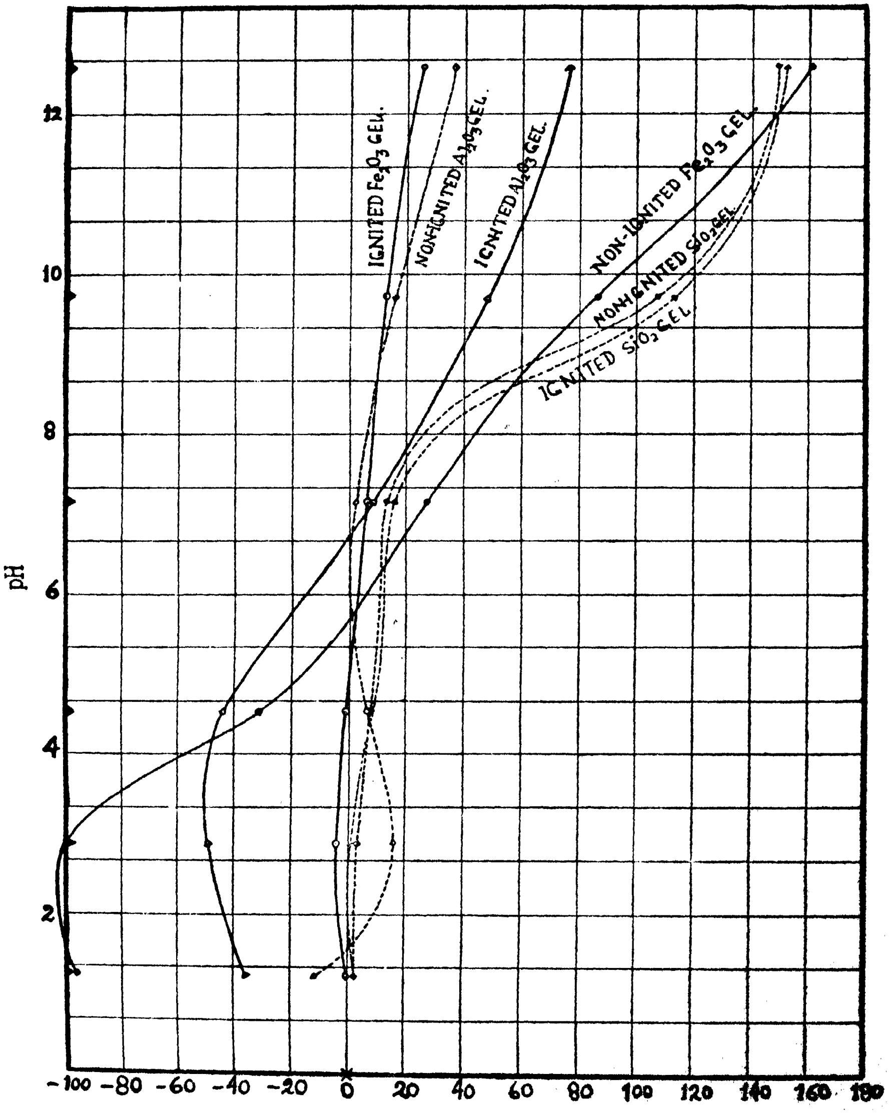

FIG. 1. Milli-equivalents of base taken up by 200 gm. of oven-dry material

TABLE I

Uptake of base with non-ignited and ignited electrodialysed gels of iron oxide, alumina and silica

*p*H	Iron oxide gel		Alumina gel		Silica gel	
	Non-ignited	Ignited	Non-ignited	Ignited	Non-ignited	Ignited
1·3	—96·7	0	—11·1	—36·3	+2·0	+2·0
2·9	—100·9	—4·0	—16·5	—48·7	2·0	1·0
4·6	—30·8	—1·0	—5·4	—42·7	6·9	7·0
7·1	+27·1	+5·8	+1·3	+7·5	12·7	15·8
9·8	86·3	12·5	16·8	47·6	106·9	112·7
12·5	160·8	25·0	36·3	75·9	147·8	151·0

The buffer curves of iron oxide ignited and fresh are in general agreement with the conclusions made by Hardy [1931] that ignited ferric oxide is much less active than the same substance in the non-ignited state. Actually the base-combining capacity of the ignited ferric oxide gel is almost nil throughout the *p*H range studied.

Also the relative base-combining capacities of electrodialysed alumina and ignited alumina gels show the same agreement with the Hardy's view in that the base-combining capacity of ordinary alumina gel is much less than that of ignited gel. The buffer curves of ordinary electrodialysed silica gel and of ignited silica gel are on the other hand almost coincident. In the latter case no negative adsorption is at all found which may be explained as being due to its strong acidic nature.

A peculiar behaviour was noticed in the buffer curves in Fig. 1 in that the base-combining capacity at *p*H 2·9 is higher than that at *p*H 1·3. This is contrary to usual expectations and may be explained as being due to the amphoteric nature of the sesquioxides. The buffer curves of silica gels show strong inflexion at *p*H 9·8. It might appear, therefore, that the inflexions at *p*H 9·8 observed with ordinary soils might be due to the presence of free silica. This point, however, requires thorough investigation. A possible explanation of this buffering action of silica gels at *p*H 9·8 might be due to the acidic nature of silica which acts with bases at high *p*H values.

Some difficulty was experienced in the titrations of the supernatant liquids obtained with ordinary electrodialysed ferric hydroxide gels and both ordinary and ignited electrodialysed gels of alumina. At low *p*H values some turbidity of the supernatant liquid was observed with both ignited and non-ignited alumina gels indicating the formation of precipitates. Actually in the case of electrodialysed iron oxide gel, formation of definite precipitates took place at *p*H 1·3 and 2·9 and a fairly deep brownish colouration at alkaline *p*H was observed. It is likely that the formation of these precipitates have a great deal to do with the peculiar behaviour of these substances in that the base-combining capacity at *p*H 2·9 is higher than that at *p*H 1·3.

Influences of free alumina on the inflexion of buffer curves

Since aluminium ion tends to pass into colloidal state at *p*H 4·6 [Britton, 1929], it was thought that free alumina might be responsible for the buffer capacities at this *p*H value. The significance of the inflexions of the buffer curves at *p*H 2·9, 4·6 and 9·8 have been discussed by Raychaudhuri and Nandymajumdar [1940]. It was thought desirable to examine whether the percentages of free alumina have any influence on the inflexions of the buffer curves at *p*H 4·6.

Table II shows the percentages of free iron oxide, free alumina and free silica of the same profiles, and also the buffer values (*d*B/*dp*H) of the soil samples at *p*H 4·6 (Fig. 2). The percentages of free iron oxide and free alumina have been determined by following the method of Hardy and Rodrigues [1939], whilst the percentages of free silica have been obtained by following the method of Truog, *et al.* [1937].

TABLE II

Percentages of free iron oxides, free alumina, and free silica and dB/dpH *values at* pH *4·6*

Locality	Soil No.	Depth	Iron oxide	Alumina	Silica	*d*B/*dp*H*
Hathwara, Manbhum, Bihar	81p	0—1 ft. 6 in.	4·29	0·14	nd.	0·00066
	82p	1 ft. 6 in.—2 ft. 3 in.	3·46	..	nd.	0·0014
	83p	2 ft. 3 in.—3 ft. 6 in.	3·55	0·13	nd.	0·0017
	84p	3 ft. 6 in.—4 ft. 11 in.	4·47	..	nd.	0·0013
	85p	4 ft. 11 in.—below	2·35	..	0·55	0·0011
Lalgarh, Midnapur, Bengal	112p	0—4 in.	4·41	0·20	nd.	0·0013
	113p	4 in.—3 ft. 4 in.	2·14	0·70	0·50	0·0010
	114p	3 ft. 4 in.—4 ft.	1·57	0·15	nd.	0·0006
	115p	7 ft.—8 ft.	nd.	0·29	nd.	0·00033
Cheerapunji, Khasi hills, Assam	124p	0—7 in.	1·24	0·09	0·37	0·00025
	125p	7 in.—10 in.	1·16	0·75	nd.	0·0033
	126p	10 in. —4 ft.	3·00	0·36	nd.	0·0030
	127p	10 ft.—below	0·55	..	nd.	0·0025

*These values of *d*B/*dp*H have been obtained from the work of S. P. Raychaudhuri and P. K. Basuraychaudhuri, which is being communicated for publication in the *Indian Journal of Agricultural Science*.

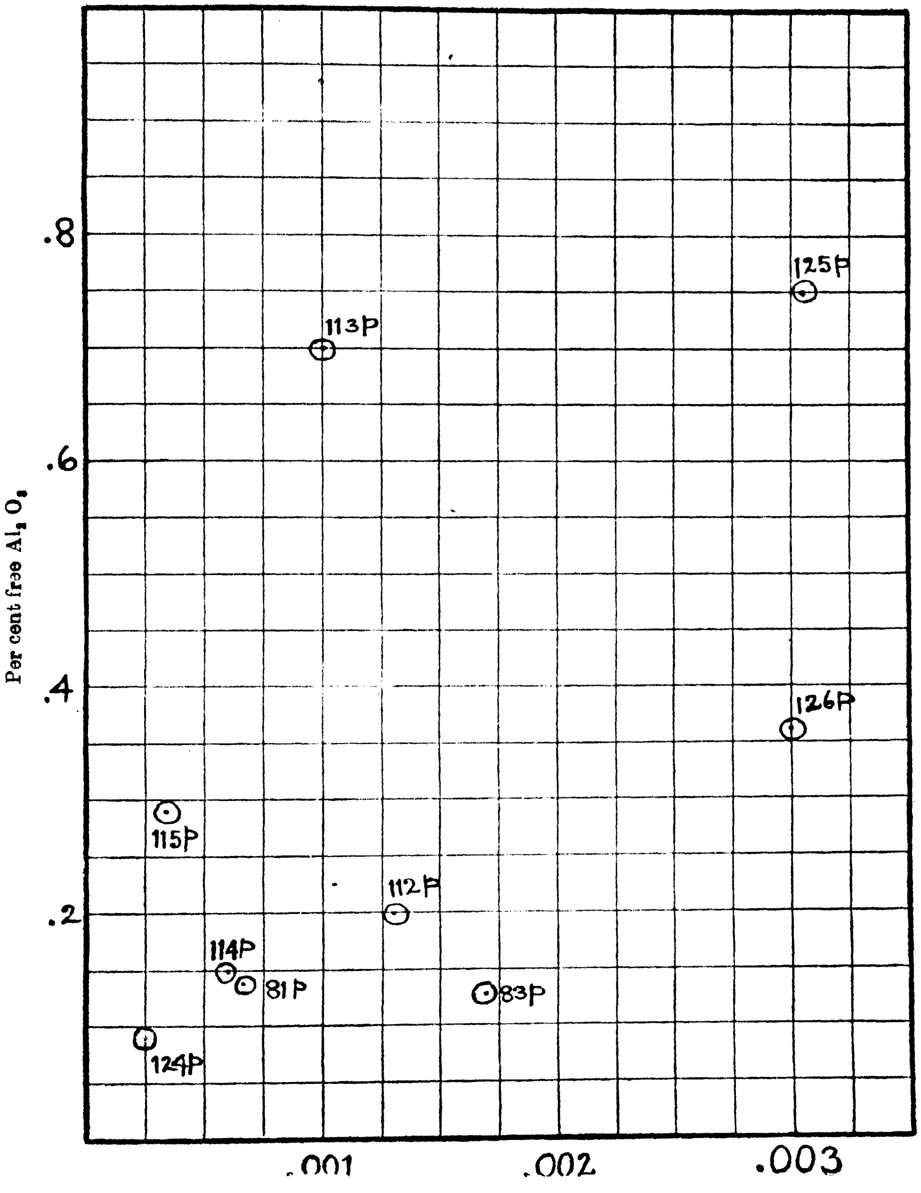

FIG. 2. dB/dpH at pH 4·6

Fig. 2 shows that there is apparently no definite correlation of the buffer values with the percentages of free alumina.

Effect of removal of free silica, alumina, and iron oxide on buffer curves

Three soils were chosen for this experiment (85p, 113p and 124p). The amorphous products of weathering, mainly the free silica, free alumina and free iron oxide in these soils, were removed by Truog's treatment, and the buffer curves of the residues were drawn with lime buffers. The results are given in Table III where the corresponding data of the ordinary air-dry soil are also included.

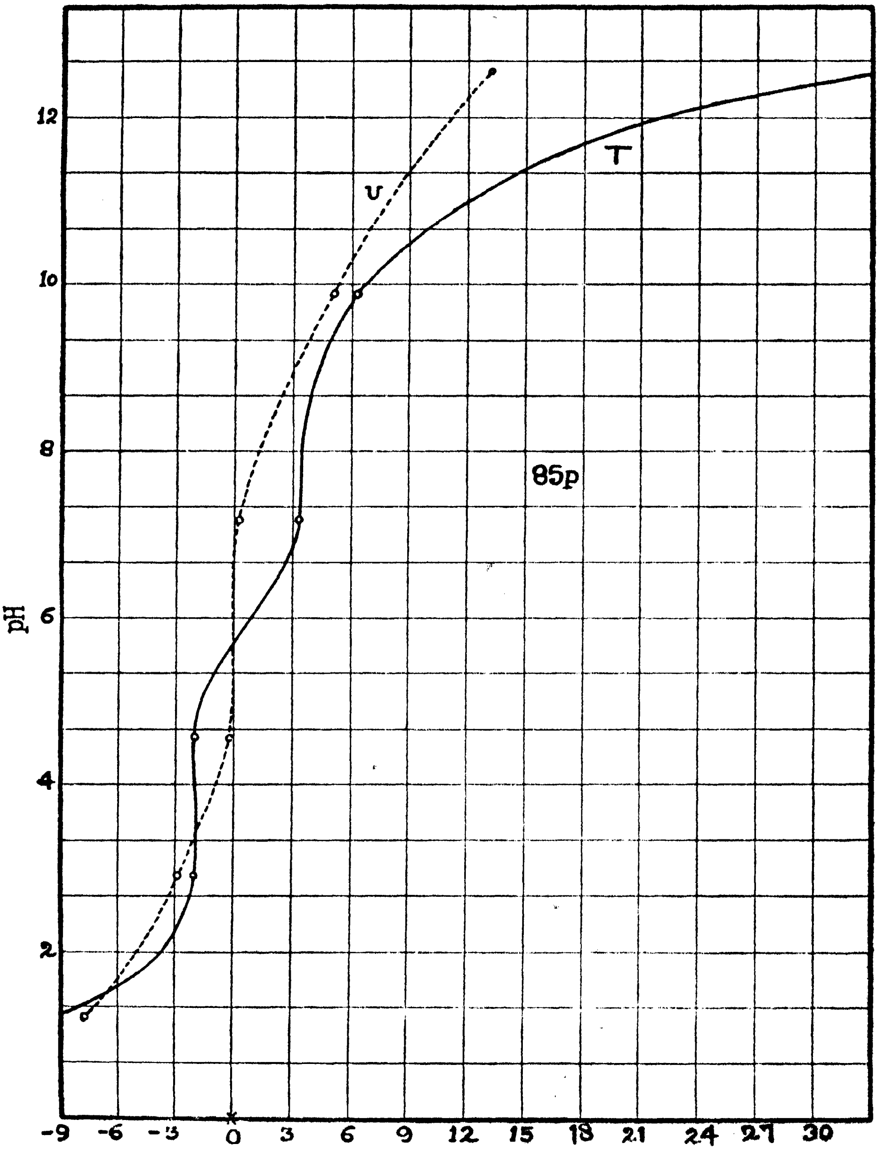

FIG. 3. Milli-equivalents of base taken up by 100 gm. of oven-dry soil

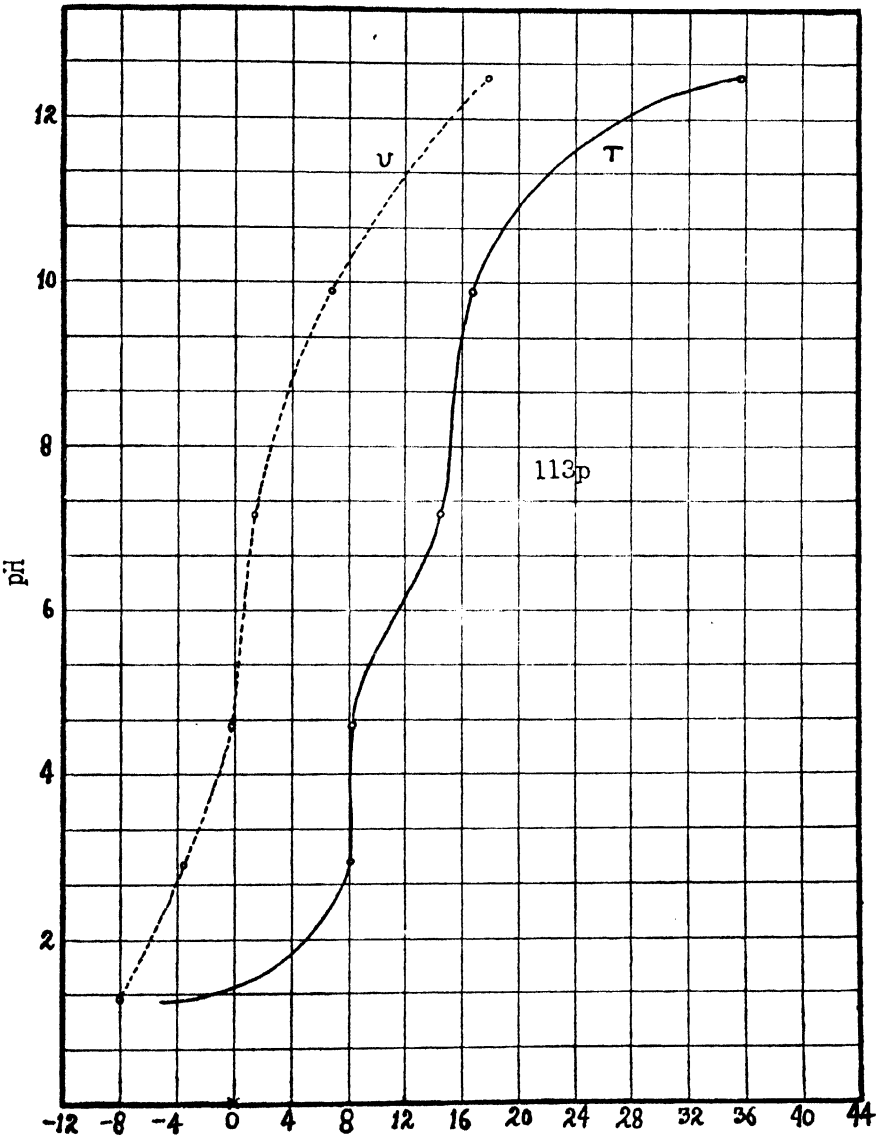

FIG. 4. Milli-equivalents of base taken up by 100 gm. of oven-dry soil

Figs. 3, 4 and 5 show respectively the buffer curves of the soils 85p, 113p and 124p before and after Truog's treatment. In the graphs the buffer curves of the untreated soils have been described as ' U ', whilst the buffer curves of treated soils as ' T '. It will be seen that, in accordance with ordinary expectations, the buffer curves of treated soils are flatter than those of the untreated ones, indicating that the removal of the gels of silica, alumina and iron oxide concentrate the residue with respect to active base-combining materials, so that a certain weight of the residue would possess higher base-combining capacities than the same weight of untreated soil. It will be seen also that all the treated soils show somewhat buffering action at *p*H 7·1 and that the untreated soils 85p and 113p show strong buffering action at *p*H 2·9.

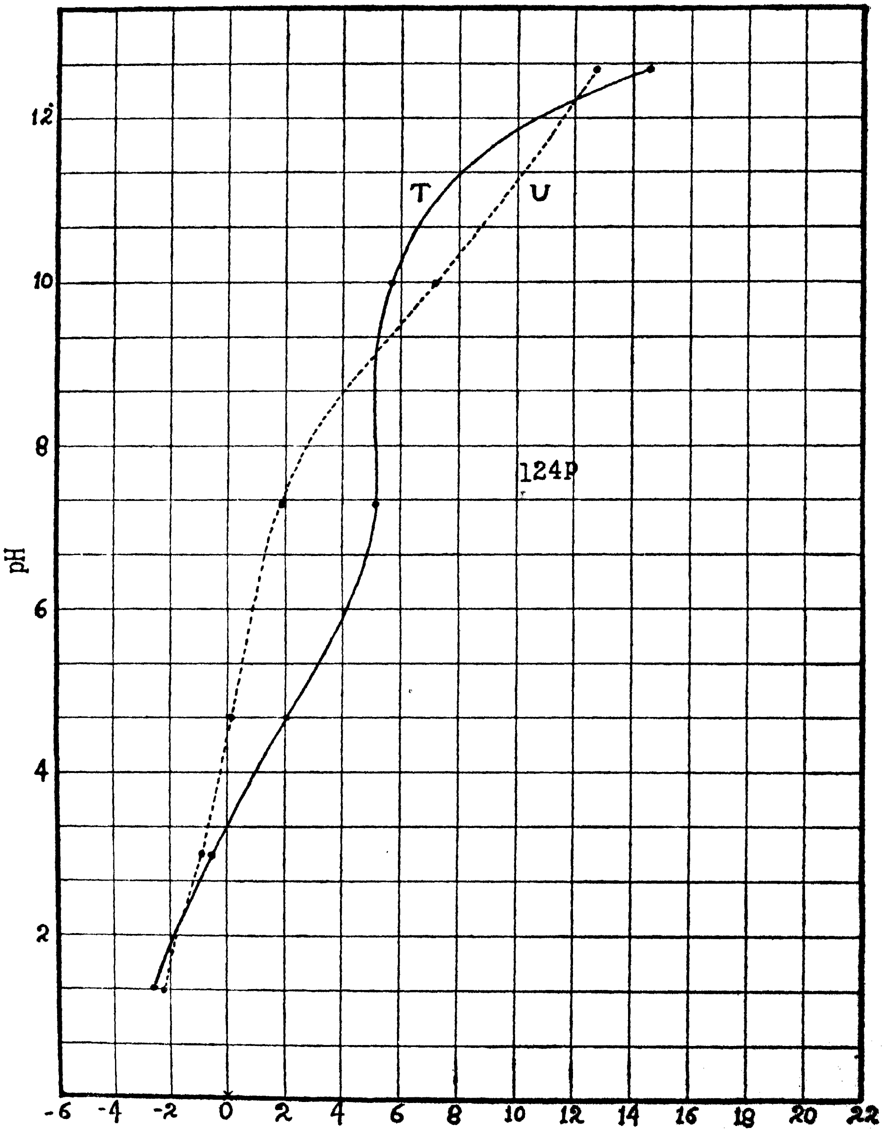

FIG. 5. Milli-equivalents of base taken up by 100 gm. of oven-dry soil

TABLE III

Uptake of base in milliequivalent by 100 gm. of soil in the ordinary air-dry conditions and after removal of free silica, free alumina, and free iron oxide by Truog's method

*p*H	85p		113p		124p	
	Un-treated	Truog-treated	Un-treated	Truog-treated	Un-treated	Truog-treated
1·3	—7·6	—9·7	—8·0	—5·1	—2·2	—2·5
2·9	—2·9	—2·0	—3·7	+8·2	—0·82	—0·61
4·6	—0·71	—2·0	—0·66	8·2	+0·18	+2·0
7·1	+0·69	+3·3	+1·3	14·5	1·8	5·0
9·8	5·1	6·3	6·9	16·8	6·9	5·5
12·5	13·4	34·3	17·6	35·6	12·5	14·3

SUMMARY

1. Buffer curves of the following substances have been studied :—

(*i*) Ignited and non-ignited electrodialysed iron oxide gel,
(*ii*) Ignited and non-ignited electrodialysed alumina gel, and
(*iii*) Ignited and non-ignited electrodialysed silica gel.

The buffer curve of ignited iron oxide gel is much steeper than that of the non-ignited one. Actually the base-combining capacity of ignited ferric oxide gel is almost nil throughout the *p*H ranges studied. On the other hand, ignited alumina gel possesses much more buffer capacity than the non-ignited one.

The buffer curves of ordinary electrodialysed silica gel and of ignited silica gel are almost coincident.

2. There is apparently no regular variation of the buffer values of soils studied, at *p*H 4·6, with the percentages of free alumina.

3. Three soil samples were freed from the amorphous products of weathering, viz. free silica, free alumina and free iron oxide, and the buffer curves of the residues were compared with those of the original soils. The buffer curves of the treated soils are found to be flatter than those of the untreated ones.

ACKNOWLEDGEMENTS

The authors express their thanks to Dr J. K. Chowdhury for his kind interest in the work and to the Imperial Council of Agricultural Research whose grant to the Dacca University has made this work possible.

REFERENCES

Drosdoff, M. and Truog, E. (1935). *J. Amer. Soc. Agron.* **27**, 312-7
Hardy, F. (1931). *J. agric. Sci.* **21**, 150-66
Hardy, F. and Rodrigues, G. (1939). *Soil Sci.* **48**, 361-84
Mattson, S. (1926), *J. Amer. Soc. Agron.* **18**, 458
Raychaudhuri, S. P. and Nandymajumdar, A. B. (1940). *Indian J. agric. Sci.* **10**, 62-81
Raychaudhuri, S. P. and Sulaiman, M. (1940). *Indian J. agric. Sci.* **10**, 158-63
Schoefield, R. K. (1933). *J. agric. Sci.* **23**, 252-4
Truog, E. *et al.* (1937). *Proc. Soil Sci. Soc. Amer.* **1**, 101-12

STUDIES ON LATERITE AND RED SOILS OF INDIA

I. INTRODUCTION

BY

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(Received for publication on 15 January 1940)

LATERIZATION is a common soil-forming process in humid tropics like India, where probably more than one-fifth of the total culturable land belongs to the laterite type. The word 'probably' is inserted deliberately since there has been of late a growing tendency in other countries of classing no longer into the lateritic group many red soils which in the past were taken to be laterite soils. Nevertheless, processes involved in the production of these red soils are intimately connected with laterization.

Both the laterite and the red soils are usually poor in fertility. In view of the fact that these soils occupy such vast areas in India, any research which may eventually lead to their amelioration would seem justified. The Royal Commission on Agriculture in India strongly recommended the carrying out of such investigations.

Apart from practical utility, researches leading to the clarification of ' what is a laterite ' are of fundamental scientific interest in this country because the word ' laterite ' originated in India. At the present moment there seems to be no definite understanding among pedologists, who have studied such soils in the past, as to the proper definition of this type of soil. Buchanan [1807] first gave the name ' laterite ' to surface formations with cellular concretions in Malabar in India. But since then red-coloured soils of the tropics were often designated as laterites [Joffe, 1936]. The researches of Bauer [1898, 1907] brought out the important point that the characteristic feature of the weathering process responsible for the formation of laterites is an accumulation of large quantities of free alumina. This offered an exact chemical index, and efforts followed to evolve a chemical definition of laterite.

The author is of opinion that these efforts were rather unfortunate because instead of clarification they made the issue of defining laterite more confused. The world at large is not likely to accept any of the chemical definitions.

The morphology and chemistry of laterite soils are not yet fully known [Joffe, 1936]. But, whereas the study of the profile characteristics of these soils has progressed considerably in other parts of the world, a detailed bibliography of which is given elsewhere [Robinson, 1932; Harrassowitz 1926], it has not yet received the attention it deserves in India.

The work on the laterite and red soils of India was originally started by the author and his colleagues [Chakraborty and Sen, 1932; 1935] in an attempt to find a method for the mechanical analysis of such soils. A method in due course was elaborated [Chakraborty, 1935] which with slight modification [Chakraborty, 1936, 1938] was found to be suitable for all types of soil.

For the above work a number of samples of soil were secured from the Directors of Agriculture of several provinces in India as soil samples from the so-called laterite areas in their respective provinces. An opportunity was thus obtained to gain further information on these laterite and red soils of India, and in the next three parts in this series certain physico-chemical measurements made on some of these soils are reported. In the fifth part the chemical definition of laterite soils is discussed. Soils used in these four parts are described in Table I ; these are all surface soils. The sixth part describes the profiles of some of the laterite and red soils of India. Further study of the morphology and chemistry of these soils is in progress the results of which will be communicated for publication in due course.

TABLE I

Locality, colour, organic matter, moisture in air-dry soil, lime content and p*H of supposed laterite soils of India*

Lab. No.	Province	Locality	Colour	Organic matter (per cent)	Moisture in air-dry soil (per cent)	Lime content as $CaCO_3$ (per cent)	pH
80	Assam .	Satgaon .	Light red	1·8	4·2	Trace	5·0
88	Do. .	Shillong .	Dark brown	6·8	6·3	*Nil*	4·8
78	Do. .	Sibsagar .	Yellow	0·90	3·1	*Nil*	4·6
38	Bengal .	Bankura .	Light red	0·30	1·5	*Nil*	6·4
44	Do. .	Birbhum .	Light yellow with a tinge of brown.	0·60	1·1	*Nil*	6·1
98	Do. .	Dacca . .	Do. .	1·30	1·8	*Nil*	5·6
1	Bihar . .	Giridih .	Deep red	0·64	2·9	Trace	7·2
70	Do. . .	Ranchi .	Light yellow with a tinge of brown	0·92	2·3	*Nil*	5·5
11	Do. . .	Deoghar .	Yellowish brown . .	1·5	2·0	*Nil*	6·7
74	Orissa . .	Bhubaneswar	Do. . .	0·90	2·6	*Nil*	6·5
72	Do. . .	Puri . .	Light yellow . . .	0·76	2·1	*Nil*	5·6
58	Bombay .	Kumata .	Red	2·40	5·6	*Nil*	6·0
56	Do. .	Belgaon .	Dark brown	2·45	6·1	*Nil*	7·4
20	Burma .	Insein . .	Light red	0·80	1·0	Trace	5·3
64	Do. . .	Tenasserien .	Dark brown	4·1	3·0	*Nil*	5·7
60	Do. . .	Do. .	Yellow with a tinge of brown	2·0	4·1	Trace	7·7
90	Do. .	Akyab .	Light yellow with a tinge of brown	1·1	1·8	*Nil*	6·8
24	Central Provinces	Raipur .	Red	1·1	1·9	0·034	7·6
30	Madras .	Taliparamba	Dark brown	10·2	6·3	Trace	5·4
34	Do. .	Calicut .	Red	1·9	4·0	Trace	5·1
32	Do. .	Kasuragod .	Deep red	1·28	3·4	*Nil*	4·8
26	Do. .	Guntur .	Do.	0·32	1·4	Trace	7·7

ACKNOWLEDGEMENTS

The work on the laterite and red soils of India of which this forms the introduction was undertaken by the Chemistry Department of the University of Dacca with financial aid from the Imperial Council of Agricultural Research. My thanks are also due to Mr J. N. Chakraborty for some of the data given in Table I.

REFERENCES

Bauer, M. (1898, 1907). [Quoted by J. S. Joffe in *Pedology*, p. 367 : Rutgers Univ. Press : 1936]

Buchanan, H. F. (1807). *Journey from Madras, Canara, and Malabar* : London, Vol. 2

Chakraborty, J. N. (1935). *Indian J. agric. Sci.* **5**, 3

——————(1936). *Soil Sc.* **42**, 261

——————(1938). *Indian J. agric. Sci.* **8**, 829

Chakraborty, J. N. and Sen, A. T. (1932). *Indian J. agric. Sci.* **2**, 516

—————————— (1935). *Indian J. agric. Sci.* **5**, 1

Harrassowitz, H. (1926). *Fors. der. Geo. und Palaen.* **4**, 253

Joffe, J. S. (1936). *Pedology*, p. 366-7 : Rutgers Univ. Press

Robinson, W. G. (1932). *Imp. Bur. Soil Sci. Tech. Com.* No. **24**

STUDIES ON LATERITE AND RED SOILS OF INDIA

II. CERTAIN PHYSICAL CONSTANTS AND THEIR RELATION TO THE CONTENT AND THE COMPOSITION OF CLAY

BY

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(Received for publication on 15 January 1940)

(With three text-figures)

THE fact that soils exhibit certain characteristic physical properties has led a number of investigators—prominent amongst whom are Briggs and associates [1907 ; 1912] in America, Keen and associates [1921 ; 1928 ; 1930] in England, Coutts [1929 ; 1930 ; 1932] in Natal and Marchand [1924 ; 1931] in Transvaal—to study the properties in detail. In general the observations were that any method based on a particular property of soils gives values which differ from soil to soil depending on the latter's nature, but for a particular soil the value is constant. The latter fact has been seized and attempts have been made to assess the general character of a soil by thus specifying it by a single number. Such methods have been given the name ' single value determinations ', and the numbers ' single value soil constants ', by Keen and Coutts [1928] who have further stressed the importance of introduction of these methods as an adjunct to the modern system of soil classification, and into soil physics.

The physical properties of laterite soils have not been extensively studied. Bennett [1926] has measured the friability and plasticity of some tropical soils and has tried to correlate them with silica/sesquioxide ratio. He finds that the figures for soils having silica/sesquioxide ratio above 2·0 are distinctly different from those in which this ratio is below 2·0. Similarly Hardy [1923] finds low sticky point and comparatively smaller linear shrinkage for soils having low silica/alumina ratio. He [Hardy, 1925] has also found comparatively low swelling coefficients and low cohesiveness for two red soils of lateritic type from Barbados and Dominica. Marchand and Vander Merwe [1926] have determined the volume expansion of the clay fractions of certain Transvaal soils. The values for soils with low silica/alumina ratio were distinctly smaller than the values of those with high silica/alumina ratio. The work of Bennett, Hardy and Marchand thus shows that lateritic soils are characteristically different in their behaviour from soils of high silica/alumina ratio.

In the publication issued by the Imperial Bureau of Soil Science [1932], in which almost all works on laterite soils up to date are summarized, it was stressed that 'data for the physical constants for soils of a laterite type are scarce'. Physical measurements on a few supposed laterite soils described in the preceding part [Sen, 1941] were made and these are here reported.

MEASUREMENTS

The following measurements were made :—

1. Hygroscopic coefficient at 50 per cent relative humidity (R)
2. Sticky point (S)
3. Loss on ignition (I)
4. Water-holding capacity (W)
5. Volume expansion (v)
6. Pore space (p)
7. Apparent specific gravity (L)
8. Real specific gravity (P)
9. Saturation capacity
10. Total exchangeable bases

The methods used for the determination are briefly as follows :—

Hygroscopic coefficient was determined by the method used by Keen and Coutts [1928]. The soil was exposed to 50 per cent relative humidity obtained by sulphuric acid-water mixture until constant weight, and then desiccated in vacuum over concentrated sulphuric acid. The loss in weight gave the hygroscopic moisture.

Sticky point was determined by the method used by Keen and Coutts [1928]. The soil is spread into a thin layer on a glass plate and water is added from a jet until the soil is definitely wet. The mass is then worked into a paste with a spatula and finally the soil is kneaded by hand until the soil just reaches the stage at which it no longer sticks to the hand or knife. At this stage it is possible to cut clean through the plastic mass with a knife.

Loss on ignition was determined by heating a weighed quantity of soil in a platinum crucible over a Bunsen flame, till constant weight was obtained.

Water-holding capacity was determined by the method used by Keen and Raczkowski [1921], as modified by Coutts [1930]. As suggested by Marchand [1924] the soil is first passed through a 100-mesh sieve and the portion failing to pass through is crushed with a wooden pestle and then mixed with the soil that passes through a 100 mesh sieve. The box used has approximately the following dimensions: height 1·5 cm., diameter 7 cm., and capacity 30 c.c.

Volume expansion, pore space, apparent specific gravity and real specific gravity were calculated from Keen-Raczkowski box experiments.

Saturation capacity was determined by the method used by Pierre and Scarseth [1931]. 10 gm. of soil were leached with 250 c.c. of normal barium acetate of pH 7·0. The soil was then leached with 250 c.c. of neutral normal ammonium chloride in order to replace barium by ammonium and the excess of ammonium chloride was removed by washing with alcohol. The absorbed ammonia was then determined by distilling with magnesia.

Total exchangeable bases were determined by the method described by Williams [1929]. 25 gm. of soil were leached with $N/2$ acetic acid. 500 c.c. of the leaching were evaporated to dryness and then gently ignited. A measured quantity of standard hydrochloric acid was then added to the residue and the excess of acid was titrated with standard alkali after filtration, using phenolpthalein as indicator.

The results are given in Tables I and II.

Hygroscopic coefficient, sticky point and loss on ignition

The correlation coefficients obtained by the above values and the clay for the Indian laterite and red soils are given below.

	I	R	S
C	0·897*	0·891*	0·900*
I	..	0·955*	0·927*
R	..	..	0·878*

* Significant at $P < 0{\cdot}01$

It will be seen that very high correlations were obtained between all the values ($P < 0{\cdot}01$). In other words the Indian laterite and the red soils conform to the general rule, viz. the heavy soils have the highest ignition losses, moisture contents and sticky points. The high values of RI and SI coefficients support Coutts' [1929] contention, who also observed similar high correlations with Natal soils, that an appreciable portion of the ignition loss is due to 'water of combination' in the clay fraction. This 'unfree water' is of course correlated with the water measured by the factors R [Keen, 1930] and S. A measurement of this unfree water of Indian laterite and red soils is reported in part III of this series.

For further examination of the association between the quantities C, I, R and S partial correlation coefficients were calculated and are given below.

$R\,C.\,I$	0·264	$R\,I.\,C$	0·779**
$R\,C.\,S$	0·483	$R\,S.\,C$	0·386
$S\,C.\,I$	0·414	$S\,I.\,C$	0·621*
$S\,C.\,R$	0·540	$R\,I.\,S$	0·787**
$I\,C.\,R$	0·340	$R\,S.\,I$	0·062
$I\,C.\,S$	0·384	$S\,I.\,R$	0·620*

* Significant at $P < 0{\cdot}05$

** Significant at $< 0{\cdot}01$

Taking the relation between R and C it will be seen that the high association between these two quantities is reduced below significance when the influence of either I or S is eliminated and that this reduction is much greater when I is eliminated than S. In other words R and I are very closely correlated, a fact which is further supported by the partial correlation values of $R\,I.\,C$ and $R\,I.\,S$.

Similarly it will be seen that the high association between S and C is also reduced below significance when the influence of any one of the factors I and R is eliminated. Here too S and I are very closely correlated as shown by the partial correlation coefficients, $S\,I.\,C$ and $S\,I.\,R$. It must, however, be pointed

TABLE I

Results of physical measurements on the laterite and red soils of India

Soil serial No.	Province	Lab. No.	Silica/sesquioxide ratio of clay fraction	Clay (per cent)	Hygroscopic coefficient	Sticky point (per cent)	Loss on ignition (per cent)	Water-holding capacity (per cent)	Volume expansion (per cent)	Pore space (per cent)	Apparent specific gravity	Real specific gravity
1	Madras	30	1·16	48·4	4·3	48·3	23·2	63·0	7·5	54·3	1·07	2·28
2	Burma	64	1·25	19·5	2·1	24·8	9·9	37·4	4·0	43·3	1·33	2·65
3	Bombay . . .	58	1·30	39·4	2·8	35·9	16·0	45·5	7·3	50·1	1·32	2·65
4	Madras	34	1·30	43·8	3·0	34·6	15·4	45·8	7·4	48·8	1·33	2·60
5	C. P.	24	1·39	17·1	2·0	17·2	9·5	25·1	2·0	40·5	1·76	2·96
6	Assam	80	1·62	27·3	1·7	31·0	9·4	39·3	8·0	44·8	1·38	2·50
7	Burma	20	1·76	12·6	0·7	19·5	3·7	26·7	2·3	36·5	1·51	2·38
8	Bihar	1	1·77	21·2	2·2	24·2	5·7	36·5	10·0	39·0	1·47	2·41
9	Bihar	11	1·90	29·2	1·5	18·2	4·8	30·6	10·0	35·5	1·58	2·45
10	Bengal	38	1·96	19·0	1·2	18·3	4·0	26·8	9·0	33·3	1·64	2·46
11	Bengal	44	2·10	9·2	0·7	15·0	2·6	23·7	8·5	30·4	1·71	2·46
12	Madras	26	2·12	12·0	1·0	12·7	3·3	22·0	4·6	32·5	1·78	2·64
13	Bengal	98	2·15	18·4	1·0	24·1	4·7	42·6	2·0	47·0	1·22	2·30
14	Orissa	74	2·16	17·2	1·5	16·4	4·9	29·2	6·7	37·2	1·60	2·55

out that although the elimination of the influence of *R* brings down the correlation between *S* and *C* just below the level of significance, the association between *R* and *S* is not very strong as shown by the value of *RS. C*. In fact the values show that the association between *R* and *C*, and *S* and *C* are much stronger than that between *R* and *S*.

Finally, the high association between *I* and *C* is also reduced below significance when the influence of either of the factors *R* or *S* is eliminated.

Taking all the above results together, it will be seen that the hygroscopic and the sticky point moistures are correlated more closely with *I* than *C*. In other words the hygroscopic coefficient and the sticky point of Indian laterite and red soils are largely controlled by the material in the soil that is driven off by ignition. The result therefore does not support the observation made by Keen and Coutts [1928], Coutts [1929], and Keen [1930] that the moisture content in the soil at half-saturation vapour pressure is controlled much more by the clay content as determined in a mechanical analysis, but it does support their observation with regard to the relationship between sticky point and the ignition loss. In fact it would appear from the high correlation between *I* and *R* and *I* and *S* obtained here that the loss on ignition is a better measure of the colloid content of the Indian laterite and red soils than the percentage of clay.

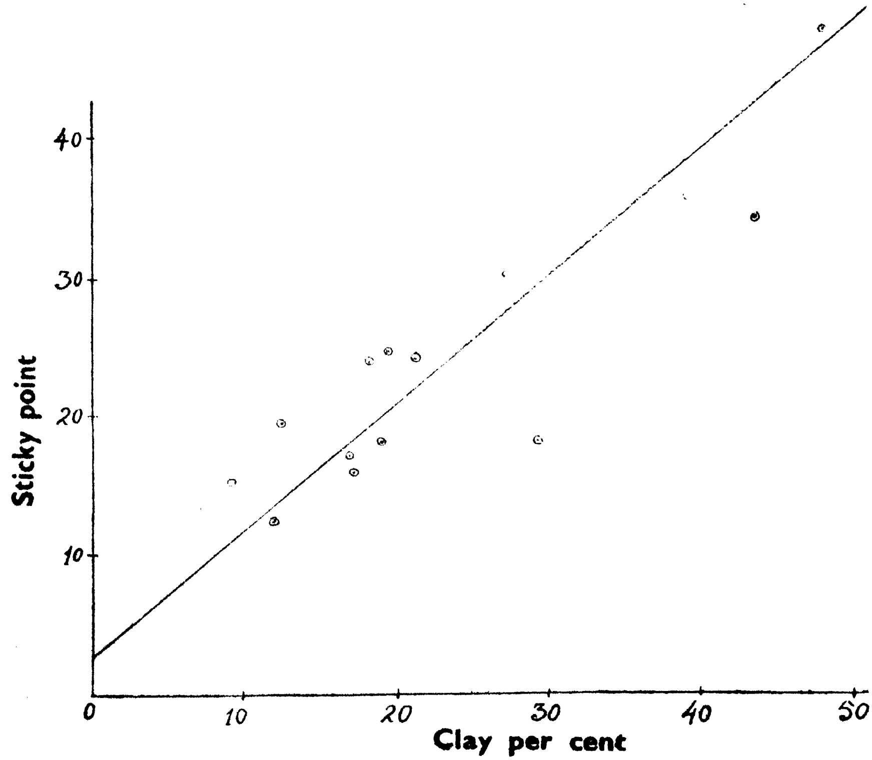

FIG. 1. Relationship between clay and sticky point

In Figs. 1, 2 and 3 the relationships between S and C, I and C, and I and S are shown graphically. The regression equations are as follows :—

$$C = 10{\cdot}78\,R + 4{\cdot}07 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$C = 1{\cdot}1006\,S - 2{\cdot}86 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$C = 1{\cdot}804\,I + 8{\cdot}79 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$S = 1{\cdot}524\,I + 11{\cdot}55 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

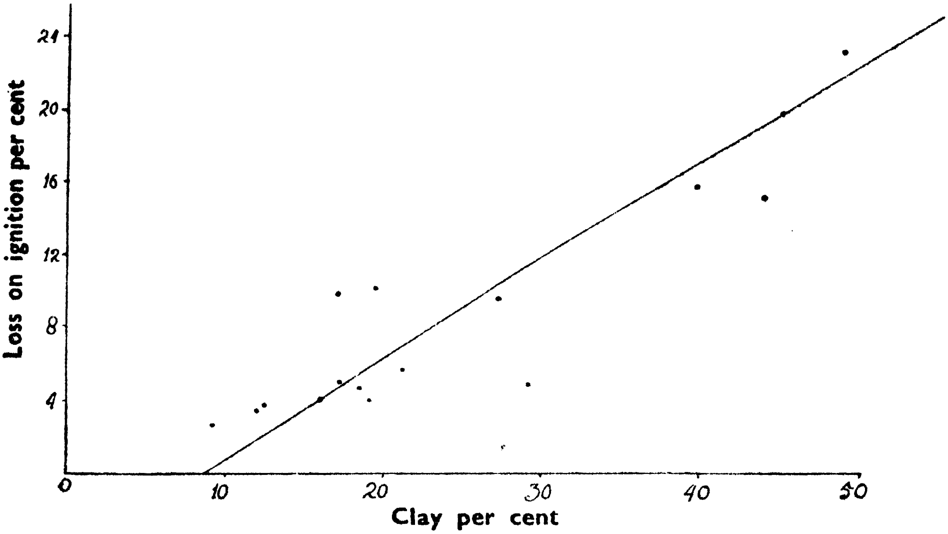

FIG. 2. Relationship between clay and loss on ignition

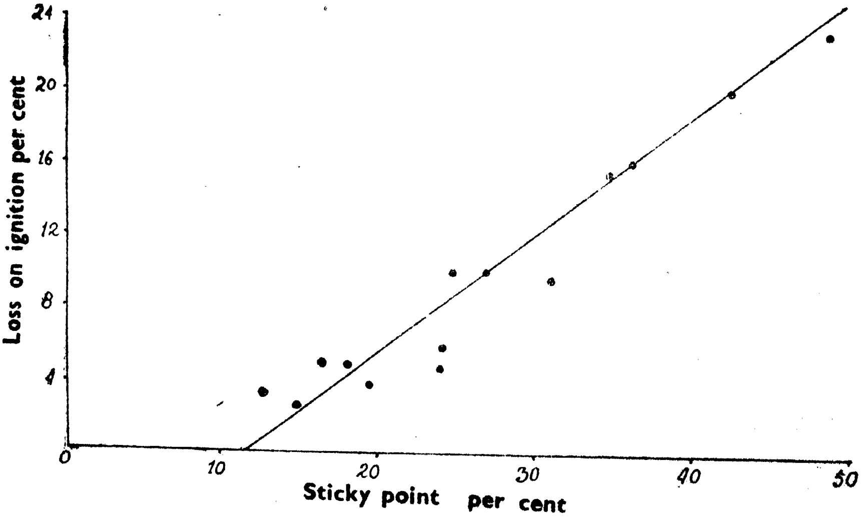

FIG. 3. Relationship between sticky point and loss on ignition

The values in equation (1) are very similar to what were obtained by Coutts [1929], viz. $C = 9\cdot1\ R + 4\cdot3$ for the tropical soils in Natal, but this was not so for the equation connecting S and I. Coutts' equation for Natal soils was

$$S = 2\cdot05\ I + 17\cdot6$$

so that when $I = 0$ (i.e. when no colloidal material was present), $S = 17\cdot6$. In other words the intersticial water for the Natal soils is 17·6 per cent which confirms the original data (16 per cent) for the intersticial water obtained by Keen and Coutts [1928] for the English soils. Later, however, Keen [1930] obtained the following equation for 250 soils from all parts of the world

$$S = 2\cdot91\ I + 7\cdot0$$

The intersticial water, i.e. when $I = 0$, is 7·0 per cent and the colloidally held water is roughly 2·91 times the ignition loss. Obviously the intersticial water and, for the matter of that, the order of correlations vary according to soil types.

From equation (4) for the soils examined here it will be seen that when $I = 0$, $S = 11\cdot55$. But substituting in equation (2), the value of C when $I = 0$ from equation (3), it will be seen that $S = 10\cdot58$. The mean of these two values may be taken as the average value of S when no colloid is present. Therefore for the Indian laterite and red soils :—

(*a*) the intersticial water averages at 11·0 per cent,
(*b*) the colloidally held water is roughly 1·5 times the ignition loss,
(*c*) the amount of colloid is roughly 1·8 times the ignition loss—equation (3),
(*d*) of the clay obtained by the mechanical analysis roughly 9 per cent on an average does not behave as clay—equation (3).

It may be of interest to compare the average values of R, S, I and the imbibitional water of the Indian laterite and red soils with those of a set of English soils containing approximately the same amount of clay. For this purpose the values obtained by Keen and Coutts [1928] for the 14 soils, viz. Nos. 2, 8, 11, 16, 17, 20, 25, 26, 29, 30, 31, 33, 35 and 37 are considered here.

The imbibitional water for the Indian and English soils is approximately $S - 11$ and $S - 16$ respectively.

	Indian soils (average of 14)	English soils (average of 14)	$\frac{\text{Indian}}{\text{English}} \times 100$
C	23·9	23·9	. .
R	1·84	2·98	63
S	24·3	35·3	69
I	8·36	7·75	108
Imbibitional water	13·3	19·3	68

The above is self explanatory and shows that the clay of Indian laterite and red soils is roughly 66 per cent as effective as the clay of soils of temperate humid countries in its colloidal behaviour and that the water of combination as indicated by the loss of ignition is higher for the former clay, an explanation for which is given later.

Water-holding capacity (W) *and pore space* (p)

The correlation coefficients obtained between the above values and the clay for the soils investigated here are given below.

$CW = 0\cdot8659$

$Cp = 0\cdot8164$

It is clear from above that here too the heavy soils have the highest water-holding capacity and pore space.

The regression equations are as follows :—

$$C = 0\cdot9296\ W - 8\cdot935 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$C = 1\cdot367\ p - 32\cdot085 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Coutts [1929] obtained for the Natal soils equal values for W and S ($\overline{W} = 44\cdot2$, $\overline{S} = 44\cdot7$) from which he concluded that W and S provide two different methods for measuring the same soil constant. With the Indian laterite and red soils, however, W is greater than S on an average by $11\cdot2$ ($\overline{W} = 35\cdot3$, $\overline{S} = 24\cdot3$). In other words

$$\begin{aligned} W &= S + 11\cdot2 \\ &= \frac{S - 11}{R} \times R + 22\cdot2 \\ &= xR + 22\cdot2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7) \end{aligned}$$

where

R = hygroscopic coefficient

$S - 11$ = vesicular coefficient according to Wilsdon [1921 ; 1924].

It will be seen that equation (7) is very similar to Briggs and Shantz [1912] equation which according to Wright [1928] reduces to

$W = xR + 21$

In other words the Indian laterite and red soils, unlike the Natal soils, maintain the usual water-relationships.

The value $22\cdot2$ in equation (7) is the free water in the closely-packed Indian laterite and red soils, while the average vesicular coefficient (x) for these soils is $7\cdot2$. According to Hardy [1923] this vesicular coefficient varies according to the different specific nature of the soil colloidal matter and for the west Indian red laterite soils it varies from $2\cdot4$ to $3\cdot5$, the lowest figure being given by the most typical of these. For the Indian laterite and red soils therefore the vesicular coefficient is remarkably high owing to very low hygroscopic coefficient. The significance of this high value cannot be emphasized until confirmed by more extensive study.

With regard to pore space it will be seen that when $I = 0$, i.e. when no colloid is present, the pore space of the Indian laterite and red soils averages at 30 per cent, a value which is slightly lower than the values obtained by Coutts [1929], viz. 33·5 and Marchand [1924], viz. 34·6, for the Natal and the Transvaal soils respectively.

It may be pointed out here that the mathematical calculations reported above and those which are going to be reported hereafter are interesting in so far as they give an idea of the general behaviour of Indian laterite and red soils, but the calculations are not of much practical value as an aid to identification of a laterite soil since they break down when applied to individual soils in 30-40 per cent of the cases. Similar observation was made by Marchand [1926] in the case of Transvaal soils.

Volume expansion (v), *apparent* (L) *and real* (P) *specific gravities*

The swelling of soil during wetting is obviously a factor of importance from the point of view of the field behaviour of the soil. As a general rule, heavy soils show greater swelling than light ones, and it was suggested tentatively by Keen and Raczkowski [1921] that there should be a close correlation between clay and volume expansion. Both Marchand and Coutts confirmed this, the correlation coefficients being

$Cv = 0 \cdot 87$ for the Transvaal soils

$Cv = 0 \cdot 582$ for the Natal soils

Coutts further observed that for the Natal soils

$Iv = 0 \cdot 817$

$Sv = 0 \cdot 849$

which suggest that v gives a useful measure of the colloid status of the soil in confirmation of the estimate derived from S and I.

The correlation coefficients for the soils investigated here are as follows :—

$Cv = 0 \cdot 0356$

$Iv = 0 \cdot 0912$

$Sv = 0 \cdot 1867$

Not only are the volume expansions of the Indian laterite and red soils very low (Table I) but the above correlation coefficients also show that they bear no relation to the clay or the colloid content of the soils. The behaviour of these soils in respect of swelling therefore appears to be somewhat peculiar.

With regard to the apparent and real specific gravities of the soils the correlation coefficients between these and the clay are

$CL = -0 \cdot 0711$

$CP = -0 \cdot 0132$

No relation therefore exists between the specific gravities and the clay content for the soils examined here. According to Keen and Raczkowski the sp. gravities should vary inversely as the clay content. With the Transvaal soils Marchand, however, obtained no relation between the true specific gravity and the clay content, but he observed that in general apparent sp. gravity decreased with increasing amount of clay. The apparent sp. gr., etc. of the Transvaal soils and those of the Indian laterite and red soils are given below for comparison.

	Transvaal soils	Indian soils
Apparent sp. gravity	1·27 to 1·62	1·07 to 1·78
Real sp. gravity	2·18 to 2·51	2·28 to 2·96
Volume expansion	3·7 to 45	2·0 to 10
Pores pace	33 to 57	30 to 54
Water-holding capacity	22 to 63	22 to 63
Ignition loss	1 to 9	2·6 to 23

Saturation capacity and total exchangeable bases

Saturation capacity and total exchangeable bases together with the degree of saturation and *p*H are given in Table II.

TABLE II

Saturation capacity, total exchangeable bases, degree of saturation and p*H of laterite and red soils of India*

Soil serial No.	Silica/ sesquioxide ratio (clay)	Clay (per cent)	Saturation capacity (per cent)	Total exchangeable bases (per cent)	Degree of saturation	*p*H
1 . . .	1·16	48·4	15·1	2·7	17·9	5·4
2 . . .	1·25	19·5	7·3	2·0	27·4	5·7
3 . . .	1·30	39·4	7·7	5·7	74·0	6·0
4 . . .	1·30	43·8	9·6	1·4	14·5	5·1
5 . . .	1·39	17·1	5·3	3·9	73·5	6·6
6 . . .	1·62	27·3	5·4	0·6	11·1	5·0
7 . . .	1·76	12·6	2·5	1·3	52·0	5·8
8 . . .	1·77	21·2	8·2	4·6	56·0	7·2
9 . . .	1·90	29·2	6·0	3·3	54·0	6·7
10 . . .	1·96	19·0	4·8	3·1	64·5	6·4
11 . . .	2·10	9·2	2·8	2·7	96·0	6·1
12 . . .	2·12	12·0	4·4	4·2	95·0	7·7
13 . . .	2·15	18·4	3·6	1·7	47·2	5·6
14 . . .	2·16	17·2	6·6	4·5	70·0	5·5

The correlation coefficient between saturation capacity and the amount of clay for the above soils is 0·8420 ± 0·0807. In general therefore the saturation capacity, as may be expected, is greater for the heavier soils. But the correlation coefficient between the total exchangeable bases and the clay is 0·01706. In other words, the total exchangeable bases bear no relation to the amount of clay. Crowther and Basu [1931] have observed the removal of bases from soils when subjected to the annual leaching over a wide period of years. Obviously therefore the varying leaching conditions, under which the soils under investigation developed, removed the bases and replaced them by hydrogen to varying extent. Consequently a good correlation between the total exchangeable bases and the clay content cannot be expected here. On the other hand the degree of saturation indicates the extent to which the individual soils may have been subjected to leaching. It will be seen that the soils with the low silica/sesquioxide ratios, i.e. the soils which are more leached are generally also more unsaturated. The pH values also show some correlation with the degree of saturation.

It should be pointed out that the saturation capacity of the soils measured here is very poor in comparison with that of the soils formed under humid temperate climates [Robinson, 1932] or that of the Indian dark-coloured clay soils [Puri, 1934]. The maximum and minimum saturation capacities for the Indian laterite and red soils examined here are 15 and 2·5 respectively, whereas the corresponding values for a set of soils of temperate climate are 46 and 14 respectively, or for a set of Indian dark-coloured clay soils are 67·7 and 28·0 respectively.

COMPOSITION OF THE CLAY

It has already been mentioned that Tables I and II have been arranged according to the silica/sesquioxide ratio of the clay fraction. By this arrangement, as will be seen, high clay values become associated with low ratios and low clay values with high ratios. In fact the correlation coefficient between this ratio and clay is —0·7001 ($P < 0·01$). This association is probably accidental, but it is necessary to bear this in mind so far as the present data are concerned. In view of this correlation it is to be expected that silica/sesquioxide ratio will also be inversely correlated with those physical measurements which are directly influenced by clay. It is necessary therefore to eliminate the influence of clay and calculate the partial correlations which are given below.

Correlation coefficients	Partial correlation coefficients	
MR —0·815** . . .	$MR.\,C$ —0·588*	M = Si/sesquioxide ratio
MS —0·744** . . .	$MS.\,C$ —0·3649	R = Hygroscopic coefficient
MI —0·857** . . .	$MI.\,C$ —0·726**	S = Sticky point
		I = Loss on ignition
MW —0·634** . . .	$MW.\,C$ —0·0781	W = Water-holding capacity
Mp —0·727** . . .	$Mp.\,C$ —0·377	p = pore space
MN —0·842** . . .	$MN.\,C$ —0·222	N = Saturation capacity

* Significant at $P < 0·05$; ** Significant at $P < 0·01$

It will be seen that with the elimination of the influence of clay, most of the relationships between the silica/sesquioxide ratio and the physical measurements become insignificant. Therefore, these physical constants are influenced more by the content than by the composition of the clay. But in the case of loss on ignition, the composition of the clay has a profound influence on it. A low silica/sesquioxide ratio implies a relatively high proportion of ferric oxide and alumina in the soil. Since these oxides generally occur in the hydrated state, one may expect the loss on ignition, or more strictly the water of combination, to increase with a decrease in the ratio. Consequently soils with low silica/sesquioxide ratio will generally have high water of combination as measured by the loss on ignition. This probably explains why the Indian laterite and red soils were found to have higher average loss on ignition than the English soils.

SUMMARY

1. A number of physical constants of laterite and red soils of India have been determined with a view to obtaining data which are practically absent for these soils.

2. It is found that these soils conform to the general rule, viz. the heavy soils have the highest ignition losses, moisture contents, sticky points, etc. Volume expansion, apparent and real specific gravities and the total exchangeable bases, however, bear no relation to the clay content.

3. From a statistical examination of the data it is found that the hygroscopic coefficient and the sticky point are correlated more closely with the loss on ignition than with the clay content. The loss on ignition is therefore a better index of the colloid content of these soils than the percentage of clay.

4. From a comparison of the data for these soils with those for some English soils with the same average clay content it is deduced that these soils have about two-thirds of the colloidal efficiency shown by the English soils. But the water of combination as measured by the loss on ignition is higher for these Indian soils.

5. For the soils examined here the colloidally held water is roughly 1·5 times the ignition loss, and the intersticial water and the vecicular coefficients average at 11·0 per cent and 7·2 per cent respectively. The significance of this high vesicular coefficient cannot be emphasized until confirmed by more extensive study.

6. The soils with low silica/sesquioxide ratios of their clay fraction are generally more unsaturated. The *p*H of the soils also vary with the degree of saturation.

7. The loss on ignition is considerably influenced by the composition of the clay also, the soils with low silica/sesquioxide ratios having the highest ignition losses. The other physical constants are influenced more by the content than by the composition of the clay.

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REFERENCES

Bennett, H. H. (1926). *Soil Sci.* **21**, 349

Briggs, L. J. and McLane, J. W. (1907). *U. S. Dept. Agric. Bur. Soils Bull.* **45**

Briggs, L. J. and Shantz, H. L. (1912). *U. S. Dept. Agric. Bur. Plant Ind. Bull.* **230**

Coutts, J. R. H. (1929). *J. agric. Sci.* **19**, 325

——— (1930). *J. agric. Sci.* **20**, 407

——— (1932). *J. agric. Sci.* **22**, 200

Crowther, E. M. and Basu, J. K. (1931). *J. agric. Sci.* **21**, 689

Hardy, F. (1923). *J. agric. Sci.* **13**, 243 ; 340

——— (1925). *J. agric. Sci.* **15**, 420 ; 434

Imperial Bureau of Soil Science (1932). *Tech. Comm.* **24**

Keen, B. A. (1930). *Proc. Sec. Internat. Cong. Soil Sci.* (*Moscow*). *Com.* **1**, 1

Keen, B. A. and Coutts, J. R. H. (1928). *J. agric. Sci.* **18**, 740

Keen, B. A. and Raczkowski, H. (1921). *J. agric. Sci.* **11**, 441

Marchand, B. de C. (1924). *J. agric. Sci.* **14**, 151

——— (1926). *S. Afr. J. Sci.* **23**, 238

——— (1931). *J. agric. Sci.* **21**, 324

Marchand, B. de C. and Van Der Merwe, C. R. (1926). *Mem. S. Afr. Dept. Agric. Div Chem. Ser.* **64**

Pierre, W. H. and Scarseth, G. D. (1931). *Soil Sci.* **31**, 99

Puri, A. N. (1934). *Soil Sci.* **37**, 105

Robinson, G. W. (1932). *Soil.*, p. 110 : Thomas Murby & Co., London.

Sen, A. T. (1941). *Indian J. agric. Sci.* **11**, 614-6

Williams, R. (1929). *J. agric. Sci.* **19**, 589

Wilsdon, B. H. (1921). *Mem. Dept. Agric. India* (*Chem. Ser.*) **6**, No. 3

——— (1924). *J. agric. Sci.* **14**, 473

Wright, C. H. (1926). *J. agric. Sci.* **16**, 18

STUDIES ON LATERITE AND RED SOILS OF INDIA

III. LOSS OF MATERIALS AT HIGH TEMPERATURE

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(With two text-figures)

IN the previous part [Sen and Deb, 1941] hygroscopic coefficient and loss on ignition of the soils have been determined. Hygroscopic moisture is the water which the colloidal material of the soil will adsorb from water vapour. Besides this there is another water which is constitutionally or chemically combined with the clay. The latter is usually taken to be the water which is not driven at 110°C. but is removed at ignition. It may therefore be calculated as the difference between the loss on ignition of a soil and loss of moisture at 110°C. *plus* the organic matter present in the soil. The works of Robinson and Holmes [1924] and Holmes and Edgington [1930] show that the combined water varies inversely with silica/sesquioxide ratio. Baver and Horner [1933] confirm these results in a general way, finding that the combined water decreases with an increasing ratio. They also suggest that the water loss-temperature curves, give some index of the nature of the base-exchange complex. But they seriously question the arbitrary use of 110°C. as representing the temperature at which all adsorbed water is driven off. Harrassowitz [1926] used the amount of combined water in soil to determine the presence of free aluminium oxides. If the water content exceeds 13·92 per cent, which is the amount contained in Kaolin, free Al_2O_3 is taken to be present.

The authors [Sen and Deb, 1941] have also found that the loss on ignition is highly inversely correlated with the silica/sesquioxide ratio of the clay fraction when the influence of clay is eliminated. Since a low silica/sesquioxide ratio implies a relatively high proportion of ferric oxide and alumina which usually occur in the soil in the hydrated state, it follows that soils with low silica/sesquioxide ratio will generally have high water of combination as measured by the loss of ignition.

The loss of matter in soil at temperatures ranging from 50°C. to about 1,000°C. has been determined by Coutts [1930, 1932]. From the trend of the curves between the temperature and percentage loss he concludes that the loss in the weight of the soil can be mainly ascribed to loss of free and interstitial water up to about 110°C., to loss of organic matter between 110°C. and 250°C., to loss of chemically combined water at higher temperature.

It thus appears that a measurement of the chemically combined water is possible either as the difference between the ignition loss of soil and loss of moisture at 110°C. *plus* the organic matter or as suggested by Coutts. And that such measurements may throw some light not only on the colloidal complex of soils but also on the presence of free sesquioxides in them. In this part the results of investigation on such measurements on laterite and red soils of India will be discussed.

EXPERIMENTAL DETAILS

Four soils of varying silica/sesquioxide ratios were selected to include soils of high and low clay contents, organic matter and loss on ignition. About two gram portions of these soils were taken in suitable porcelain boats and were exposed in an atmosphere of water vapour at 50 per cent relative humidity until constant weight. They were then heated in an electric furnace at different temperatures up to 600°C. The temperature was measured by a number of sensitive thermometers giving ranges of temperatures. It was observed that there was a gradual fall of temperature from the centre to either mouth of the furnace tube. This fall was carefully noted. By suitable contrivance the boats were placed on either side of the centre so that maximum fall in temperature from the centre to the furthest end of the boats did not exceed 2°C. The boats were heated to constant weight at each selected temperature.

EXPERIMENTAL RESULTS AND DISCUSSION

In Table I are given the losses at different temperatures of the four soils together with their silica/sesquioxide ratio, clay contents, organic matter and loss on ignition over Bunsen burner.

The figures in the table show that as the temperature increases the loss in soil in all cases also becomes greater until at temperature 550°C.-600°C. no further loss takes place. The total loss at the latter temperature is equal to the loss on ignition over Bunsen burner. Since the ignition temperature over Bunsen burner is about 900°C., it appears that no further change takes place in a soil leading to its loss once it is heated up to 600°C.

It has already been stated that there are two ways of obtaining the combined water (W) in soil. According to Coutts it is

$$W = \text{Ignition loss—the loss at } 250^\circ\text{C.} \qquad (1)$$

The usual older method is

$$W = \text{Ignition loss—(loss at } 110^\circ\text{C.} + \text{organic matter)} \qquad (2)$$

TABLE I

Percentage losses at different temperatures of soils together with their silica/sesquioxide ratios, clay and organic matter contents and loss on ignition

Soil (Lab.) No.	30	64	80	20
Silica/sesquioxide ratio	1·16	1·25	1·62	1·76
Per cent clay	48·4	19·5	27·3	12·6
Per cent organic matter	10·2	4·1	1·8	. .
Per cent loss at—				
110°C.	3·81	1·54	1·36	0·55
130°C.	4·59	2·17	1·66	0·67
150°C.	5·23	2·70	2·14	0·90
170°C.	6·01	3·19	2·73	1·07
190°C.	7·57	4·00	3·35	1·38
210°C.	9·36	5·06	3·97	1·72
250°C.	12·22	6·40	4·68	1·99
300°C.	15·88	7·80	5·35	2·26
350°C.	17·77	8·32	6·92	2·31
400°C.	18·43	8·50	7·20	2·49
450°C.	21·42	9·18	8·40	3·22
500°C.	22·77	9·63	9·22	3·56
550°C.	22·91	9·73	9·33	3·62
600°C.	23·19	9·82	9·38	3·68
Loss on ignition over Bunsen burner .	23·21	9·89	9·36	3·67

Let equation (1) be considered first.

Table II shows that W/clay decreases with the increase in the silica/sesquioxide ratio, thus confirming Robinson and Holmes [1924], Holmes and Edgington's [1930], and authors' [Sen and Deb, 1941] observations. Applying Harrassowitz's views that when the percentage of combined water (i.e. $W/\text{clay} \times 100$) exceeds 13·92, which is the amount contained in Kaolin, the presence of free sesquioxide is indicated, it is to be expected that soil 30 should have the largest amount while soil 20 no free sesquioxides. The figures for free sesquioxides given in the last column of the table in a way confirm this. The discrepancy that the clay of soil 20 should contain some free sesquioxide when its combined water is less than 13·92 per cent may be explained by the fact that all the silicates in the soil are not Kaolin, and secondly in a mixture of such silicates and free sesquioxides the proportions may happen to be such that the amount of combined water may fall below 13·92 per cent, but at the same time soil may contain some free sesquioxides. Therefore the possible method of identification of laterite soils by the use of combined water appears to suffer from the same drawback as does another known method of identification of such soils (dealt with by the authors in Part V in this series) by the use of silica/sesquioxides ratio of the clay fraction. Nevertheless the results obtained above appear to confirm the generalization that temperature up to about 250°C. mainly destroys the organic matter, while higher temperatures destroy the inorganic colloids of the soil.

TABLE II

Combined water (W) *calculated according to equation* (*1*) *and* W/*clay in four Indian laterite and red soils*

Soil (Lab.) No.	Silica/ sesquioxide	*W*	$\frac{W \times 100}{\text{clay}}$	Per cent total free sesquioxide
30	1·16	11·0	20·2	28·5
64	1·25	3·5	17·5	14·2
80	1·62	4·68	16·3	8·7
20	1·76	1·68	13·2	4·4

Let equation (2) be now considered. Here *W* is taken to be equal to the difference between loss on ignition and the loss at 110°C. *plus* organic matter. In Table III, *W* is calculated according to this equation.

TABLE III

Combined water (W) *calculated according to equation* (2)

Soil (Lab.) No.	Silica/ sesquioxide	*W*	$\frac{W \times 100}{\text{clay}}$	Per cent total free sesquioxide
30	1·16	9·20	19·0	28·5
64	1·25	4·25	21·8	14·2
80	1·62	6·20	22·7	8·7
20	1·76	3·12	24·7	4·4

The most striking fact shown in Table III is that the value of $W/\text{clay} \times 100$ is very high even for soil No. 20 containing a small amount of free sesquioxides. Obviously the calculated values of W are larger than what they really should be. This shows that all the adsorbed water is not driven out at 110°C., thus giving increased values for W. Baver and Horner [1933] also found that all the adsorbed water of soil colloids is not removed at 110°C. It is clear therefore that between equations (1) and (2), the former should be employed to find out the combined water in soils.

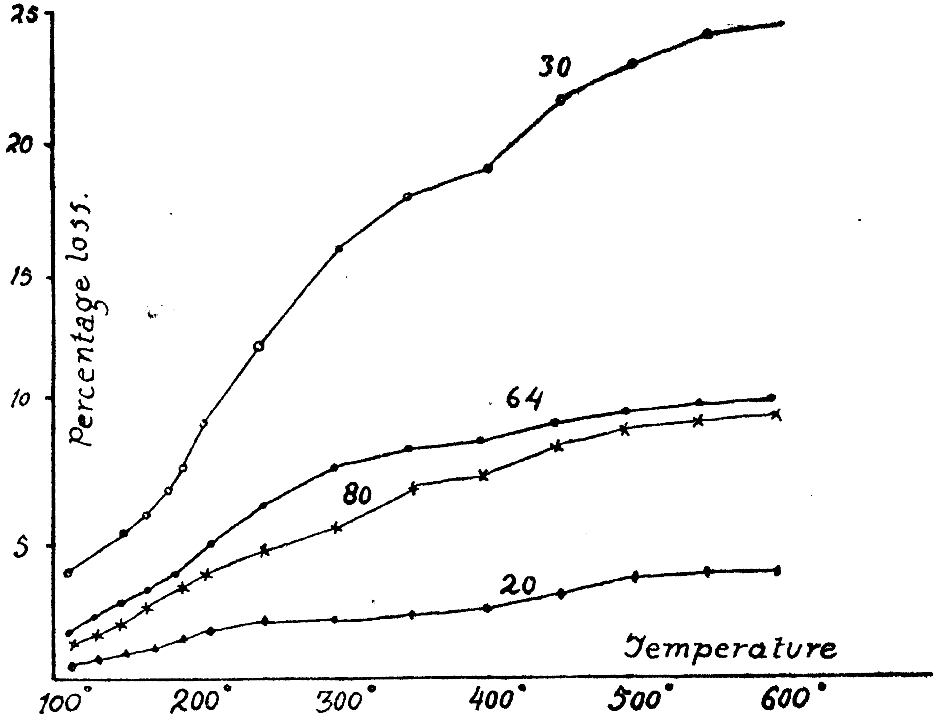

FIG. 1. Percentage of soil materials at different temperatures

In Fig. 1, the percentage loss in weight of soil is drawn against temperature and from the nature of the curves some interesting observations can be made. In all cases the loss increases linearly up to 170° C., when there is a break. From there the loss starts off at a greater rate which, however, gradually goes down until 250°C., when the rate becomes more slow. At 400°C. there is another break with an increased rate of loss which gradually falls off to zero at about 600°C. These increases and falling off in rates will be better understood from Fig. 2 in which rate of loss per 20°C. at different temperatures is given for soil No. 30. For instance the loss between 300° and 350°C. is calculated per 20°C. and plotted against 300°C. in the curve, and so for the other temperatures. The curve shows two distinct maxima, one at 190°C. and the other at 400°C. and three minima at 130°C., 350°C. and 500°C. respectively.

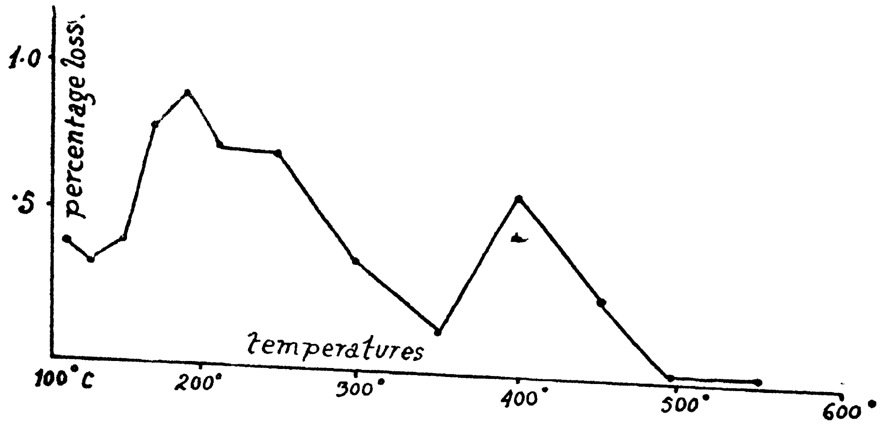

FIG. 2. Rate of loss per 20° rise of temperature of soil materials at different temperatures

The first minima corresponds to the loss of adsorbed water. Upwards of 130°C. destruction of organic matter takes place, the rate becoming maximum between 190° and 210°C. From 250°C. the loss of combined water takes place and as is to be expected the rate falls off until 350°-400°C., when it suddenly jumps up to a maximum. This the authors believe to be due to the shattering of the crystal lattice of the colloidal complex, when a further amount of combined water is exposed for evaporation. Thereafter the rate rapidly falls off until 500°-550°C., when all combined water has disappeared.

SUMMARY

(1) Four Indian laterite and red soils have been tested at different temperatures from 110°C. to 600°C. and the loss in weight of the soils at those temperatures has been determined.

(2) The results show that all the adsorbed (hygroscopic) water is not removed at 110°C.

(3) Upwards of 130°C. the loss is mainly of organic matter and at about 250°C. almost all the organic matter is destroyed.

(4) Upwards of 250°C. the loss is mainly of combined water. At 350°-400°C. the crystal lattice of colloidal complex is broken and further loss of combined water takes place.

(5) Upwards of 550°-600°C. no further loss takes place and the loss at 600°C. is equal to the ignition loss over Bunsen burner.

(6) The combined water given by the loss between 250°C. and 600°C. varies inversely with the silica/sesquioxide ratio of the clay, being larger for the laterite soils of low silica/sesquioxide ratios. When the combined water is calculated for 100 gm. of clay in the soil, a figure is obtained which indicates the presence of free sesquioxide in the soil and may be in a way utilized for identifying laterite soils,

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REFERENCES

Baver, L. D. and Horner, G. M. (1933). *Soil Sci.* **36**, 329

Coutts, J. R. H. (1930). *J. agric. Sci.* **20**, 541

——————— (1932). *J. agric. Sci.* **22**, 200

Harrassowitz, H. (1926). *Laterit. Gebr. Borntraeger* : Berlin

Holmes, R. S. and Edgington, G. (1930). *U. S. Dept. Agric. Tech. Bull.* **229**

Robinson, W. O. and Holmes, R. S. (1924). *U. S. Dept. Agric. Bull.* **1311**

Sen, A. T. and Deb, B. C. (1941). *Indian J. agric. Sci.* **11**, 617-29

STUDIES ON LATERITE AND RED SOILS OF INDIA

IV. THE POTENTIOMETRIC AND CONDUCTOMETRIC TITRATIONS OF INORGANIC COLLOIDS OF LATERITE AND RED SOILS WITH CAUSTIC SODA AND BARYTA

BY

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(With four text-figures)

TITRATION curves have often been used by the chemists in determining the absorptive capacity of colloids. Thus the method has been used with success in the case of proteins by Loeb [1922], Hollman and Godner [1925] and others, and in the case of soil by Hissink [1925], Bradfield [1927] and Baver and Scarseth [1931] and several others.

The absorptive capacity of the clay fraction of some of the Indian lateritic and red soils has been measured by potentiometric and conductometric titrations with baryta and caustic soda and results obtained will be discussed here.

EXPERIMENTAL PROCEDURE

The clay fraction (0·002 mm. and below) of the soil was obtained by following the procedure in the usual method of mechanical analysis. The organic matter in the soil was destroyed with hydrogen peroxide, and final dispersion effected with caustic soda. The clay collected by decantation was flocculated with sodium chloride and finally purified by electrodialysis. The purified clay was shaken with water for 6-8 hours and made up to one per cent suspension. Aliquot portions of the suspension were taken for titration with 0·1 *N* baryta and 0·1 *N* caustic soda which were added from microburettes. The conductometric titrations were carried out in CO_2-free atmosphere from start to end. For potentiometric titration hydrogen electrode was used.

RESULTS AND DISCUSSION

Bradfield [1927] has determined the saturation capacity of colloidal clay by various methods. He has come to the following conclusions :—

1. The baryta absorbed at *p*H 7 by an electrodialysed colloidal clay is equivalent to its exchange capacity.
2. The meeting point of two separate straight curves in the conductometric titration of colloidal clay with caustic soda gives the exchange capacity,

3. The caustic soda absorbed by a colloidal clay at pH 7 is less than its saturation capacity. The clay is saturated usually between pH 8 and 8·5 in the case of caustic soda.

4. The exchange capacity of colloidal clay cannot be determined by the conductometric titration with baryta.

TITRATION CURVES

In Figs. 1 and 2, the potentiometric and conductometric titration curves with caustic soda and baryta for a few of the clays examined are shown. The general trend of the curves are nearly the same in all cases. In potentiometric titrations it is found that in each case the amount of caustic soda required to raise the clay to any pH is less than the equivalent amount of baryta required to raise it to the same pH.

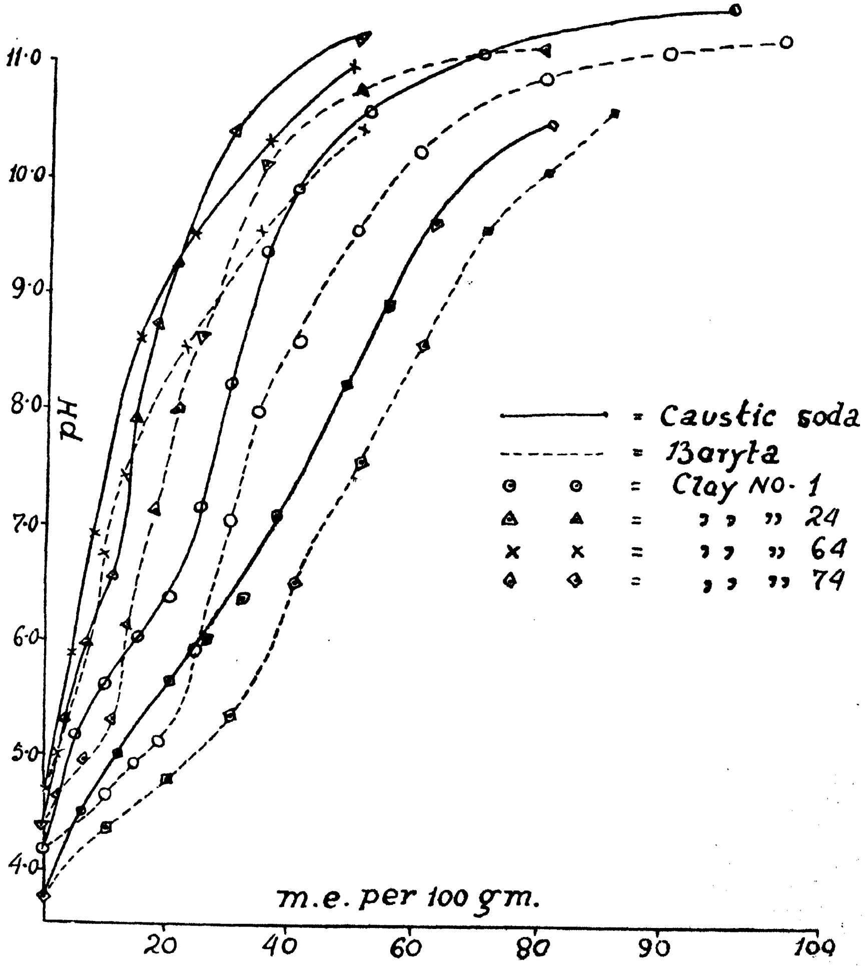

FIG. 1. Potentiometric titration curves of clay

In the case of conductometric titrations with caustic soda the complex formed with Na-ion being dissociable and somewhat soluble, the conductivity of the sol gradually increases with addition of caustic soda until the amount of caustic soda gives a rapid increase in conductivity. A second break in the curves occurs at *p*H 9·5-10·2 showing further rapid increase in conductivity. This is most probably due to the breaking up of the double bonds of alumino-silicic acid complexes of more soluble substances [Mattson, 1935]. The conductometric titrations of colloidal clay with baryta does not give any indication of its exchange capacity. In some cases the conductivity of the sol slightly diminishes when baryta is added, but in other cases it remains fairly constant until the clays are saturated to an extent of 60-80 per cent, when there is a rapid increase in conductivity.

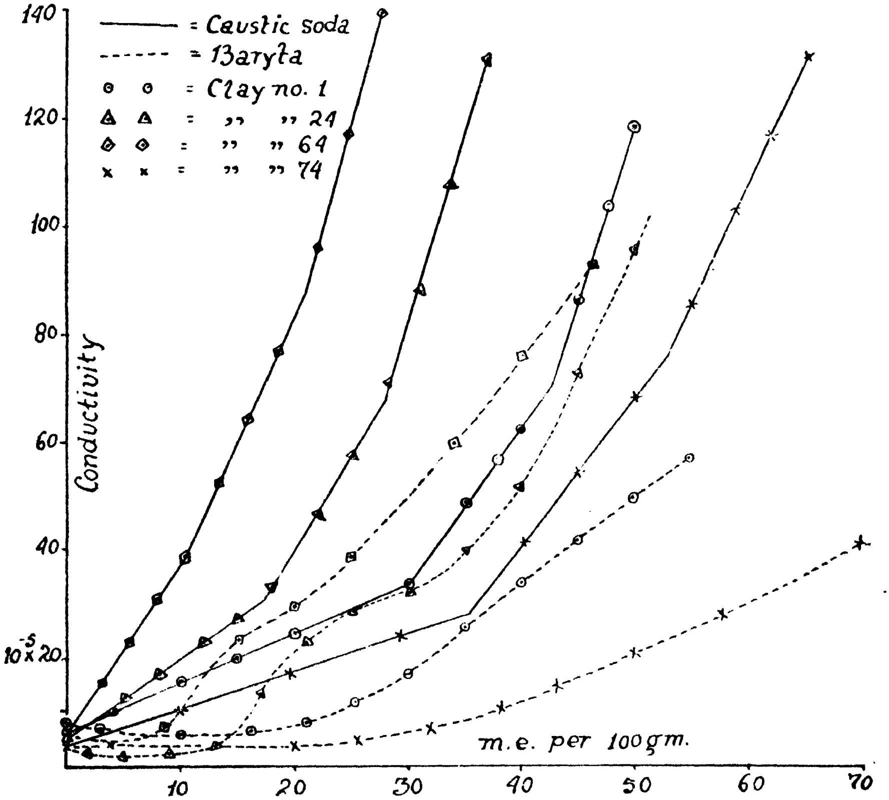

FIG. 2. Conductometric titration curves of clay

EXCHANGE CAPACITY AND ITS RELATION TO SILICA/SESQUIOXIDE RATIO

The exchange capcity by potentiometric titrations with baryta (i.e. baryta absorbed at *p*H 7) and conductometric titrations with caustic soda are given in Table I. The *p*H of clay suspension with caustic soda corresponding to the exchange capacity is also given in the table.

TABLE I

Exchange capacity of soil clays obtained by potentiometric and conductometric titrations

*Soil lab. No.	Sample from	Exchange capacity of clay		pH with caustic soda
		Potentiometric by baryta at pH 7	Conductometric first break in the curves	
64	Burma	10·5	10·5	7·8
34	Madras	11·2	11·2	8·2
24	Central Provinces	17·5	17·0	8·4
80	Assam	14·0	14·0	7·8
1	Bihar	30·0	29·5	8·2
38	Bengal	23·0	23·5	8·3
44	Bengal	32·0	31·0	8·3
74	Orissa	44·5	36·0	7·9

*The soils have been fully described in part I in this series [Sen, 1941].

It will be seen from Table I that the potentiometric titrations with baryta and conductometric titrations with caustic soda give almost identical values for exchange capacities excepting clay of soil No. 74. That the base saturation is complete at pH 7 of Ba-clay system is thus supported by a quite different method of finding the exchange capacity, viz. by the conductometric titration with caustic soda. In the case of potentiometric titration with caustic soda, however, the saturation of the clay by this base is not complete at pH 7, but at pH's ranging from 7·8 to 8·4 depending probably on the nature of the clay acids investigated here. No explanation for the variation in the exchange capacity of clay of soil No. 74 by the potentiometric and conductometric titrations can be offered.

In Table II the clays are arranged in order of their silica/sesquioxide ratios showing their exchange capacities and ultimate pH, i.e. the pH of the electrodialysed clay.

Numerous investigators have found that properties of the inorganic soil colloids vary with the silica/sesquioxide ratio. In general Table II shows that as the silica/sesquioxide ratio increases the exchange capacity increases and the ultimate pH of the clay decreases. Thus the exchange capacity of clay of soil No. 64 having silica/sesquioxide ratio 1·25 is 10·5 m.e. for 100 gm.

and 4·68 as its ultimate *p*H, whereas clay of soil No. 74 having silica/sesquioxide ratio 2·16 has an exchange capacity of 44·5 m.e. and ultimate *p*H 3·75. The relationship between the silica/sesquioxide ratio and either the exchange capacity or the ultimate *p*H is not, however, exact. But it may be mentioned that exact relationship is not possible owing to the presence of free oxides of silicon, aluminium and iron as shown by Baver and Scarseth [1931].

TABLE II

Exchange capacity and p*H of the electrodialysed clay*

Clay of soil No.	Silica/ sesquioxide ratio	Exchange capcity by potentiometric titration with baryta (m. e. per cent)	*p*H of electro-dialysed clay
64	1·25	10·5	4·68
34	1·30	11·2	4·50
24	1·39	17·5	4·35
80	1·62	14·0	4·44
1	1·77	30·0	4·16
38	1·96	23·0	4·30
44	2·10	32·0	4·03
74	2·16	44·5	3·75

When, however, the exchange capacity and the ultimate *p*H are considered together, it is found that there exists a fairly good inverse relationship between the two sets of values (Fig. 3). It appears therefore that both the exchange capacity and ultimate *p*H are governed by the same set of factors in the clay.

ABSORPTION CAPACITY AT DIFFERENT *p*H VALUES

The quantities of baryta and caustic soda absorbed by the clays at different *p*H are next calculated. A few cases are shown in Fig. 4. These quantities are obtained, following Bradfield, by the difference in the quantities of base required to raise equal volumes of clay suspension and water to the same *p*H. The graphs show that there is no precise meaning of the term 'base absorption capacity' of soil colloids as bases are absorbed continously with increasing *p*H. Thus clay of soil No. 64 absorbs 10·5 m.e. of baryta at *p*H 7 and 50·0 m.e., i.e. five times as much, at *p*H 10·5. Puri and Uppal [1939] have also drawn attention to the necessity of defining the base absorption capacity. The increase in the absorptive capacity above the saturation pH (i.e. pH 7·0-8·4) is probably due to the breaking up of alumino-silicate complex into simpler silicates and aluminates which remain firmly adhered to the surface of the original complex and may lead to the increase in the absorptive capacity of the clay. It may not be out of place to mention here that there is little or no relation between the quantities of base absorbed by clay at pH's above the saturation point (i.e. pH 7 for baryta and pH 8-8·4 for caustic soda) and the silica/sesquioxide ratios of those clays as shown in Table III

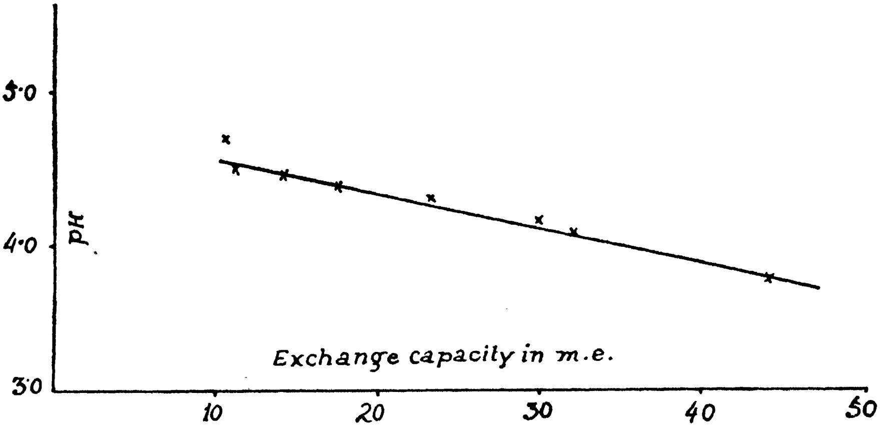

FIG. 3. Relationship between the exchange capacity and pH of the electrodialised clay

TABLE III

Silica/sesquioxide ratios and the absorption of bases by clays at p*H 10·5*

Clay of soil No.	Silica/ sesquioxide	Baryta absorbed at pH 10·5	Caustic soda absorbed at pH 10·5
64	1·25	50·0	35·0
34	1·30	36·0	26·5
24	1·39	40·0	26·5
80	1·62	42·5	28·0
1	1·77	60·0	44·0
38	1·96	43·0	34·5
44	2·10	58·5	52·5
74	2·16	80·5	75·0

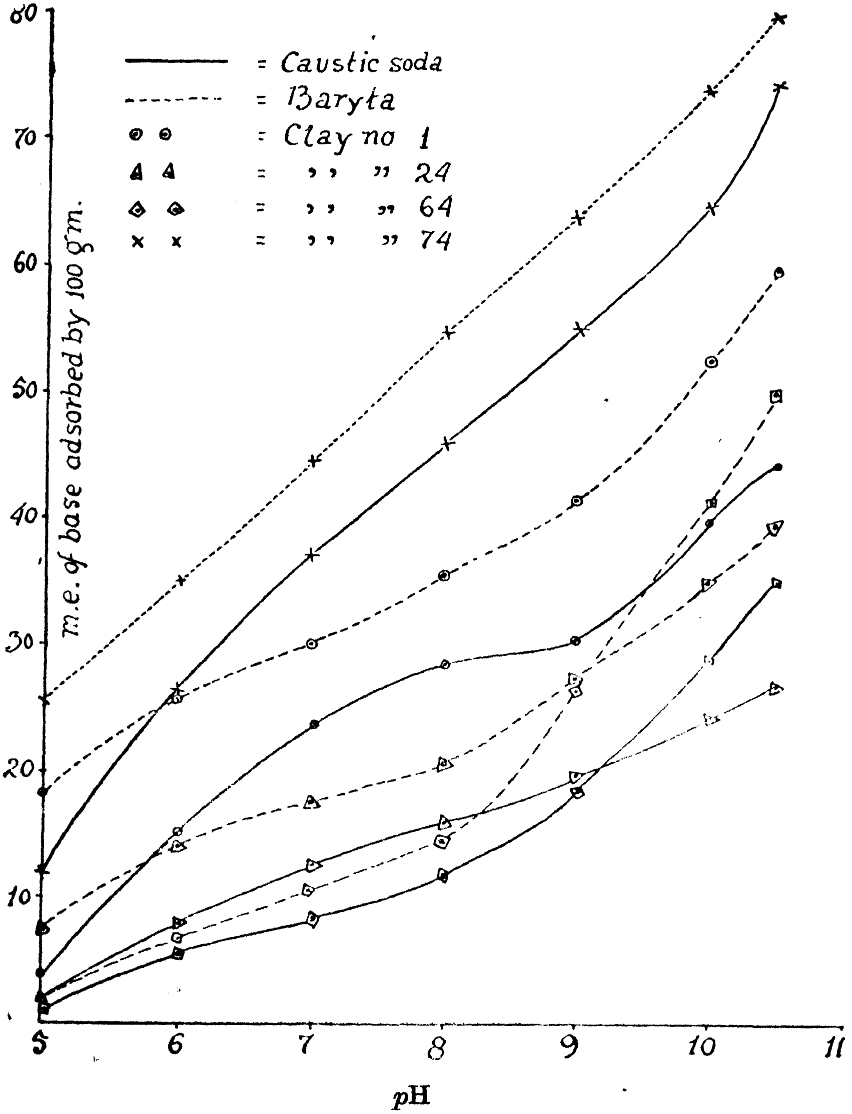

FIG. 4. Absorption of bases at different pH by electrodialysed clay

PERCENTAGE BASE SATURATION

In Tables IV and V the percentage saturation of the base at different pH's up to the saturation point with baryta and caustic soda respectively are given. They are calculated by the base absorbed (interpolated) at the particular pH, divided by the saturation capacity of the clay, multiplied by 100.

TABLE IV

Percentage saturation of base at different p*H values with baryta*

Clay of soil No.	*p*H 5·0	*p*H 6·0	*p*H 7·0
64	19·0	62·8	100
34	44·6	80·3	100
24	42·8	80·0	100
80	35·7	71·0	100
1	60·0	85·0	100
38	52·1	93·4	100
44	34·3	84·3	100
74	56·6	77·7	100

TABLE V

Percentage saturation of base at different p*H values with caustic soda*

Clay of soil No	*p*H 5·0	*p*H 6·0	*p*H 7·0	*p*H 8·0
64	11·4	52·3	78·0	112·0
34	21·4	67·4	84·8	98·2
24	11·6	45·1	71·6	91·6
80	14·2	57·1	80·0	103·0
1	11·6	50·0	80·0	96·0
38	8·7	19·5	86·0	95·6
44	12·5	61·2	93·1	98·4
74	26·6	57·7	82·2	102·2

Tables IV and V show that the base saturation takes place to different extent for different clays at the same *p*H with the same base and for the same clay at the same *p*H with different bases. Thus the base saturation with baryta varies from 19·0 to 60·0 per cent at *p*H 5·0 for the different clays while it varies from 8·7 to 52·1 per cent at *p*H 5·0 for clay of soil No. 38 with caustic soda and baryta respectively. At *p*H 7·0 the clays were saturated from 71·6 to 93·1 per cent with caustic soda. It may be pointed out that percentage saturation is an important factor in crop growth [Pierre, 1931]. The importance of the figures given in these tables is therefore self-evident.

CONCLUSION

This study was primarily undertaken to see whether the clays of the laterite and red soils of India behaved in any peculiar way so that the peculiarity may be used to characterize these soils. The data obtained, however, reveal no special peculiarity.

SUMMARY

(1) Potentiometric and conductometric titrations have been carried out with electrodialysed clay suspensions of eight Indian laterite and red soils with baryta and caustic soda.

(2) The amount of base absorbed corresponding to *p*H 7·0 in the case of baryta is taken as the base-exchange capacity of clay. Similarly the amount of base absorbed corresponding to the first break in the conductometric titration curve with caustic soda is also taken as the base-exchange capacity of the clay. The exchange capacities obtained by the two methods are found identical in seven out of eight cases.

(3) The potentiometric titration curves with caustic soda give the exchange capacity at *p*H's ranging from 7·8 to 8·4 for the clays investigated here.

(4) The conductometric titration curves with baryta are found unsuitable for the measurement of exchange capacities.

(5) The exchange capacity as well as ultimate *p*H (i.e. the *p*H of the electrodialysed clay) show a general direct and inverse relation respectively with silica/sesquioxide ratio of the clay, but the exchange capacity bears a more exact inverse relationship with the ultimate *p*H.

(6) Laterite soil clay absorbs bases continously with increasing *p*H. A clay may absorb 10·5 m.e. of baryta at *p*H 7·0 and five times as much at *p*H 10·5.

(7) There is little or no relation between the silica/sesquioxide ratios and the quantities of bases absorbed above the saturation *p*H.

(8) The percentage base saturation is different for different clays at the same *p*H with the same base and for the same clay at the same *p*H with different bases.

(9) It is thus evident that there is no special peculiarity in the behaviour of the clays of the laterite and red soils of India.

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REFERENCES

Baver, L. D. and Scarseth, G. D. (1931). *Soil Sci.* **31**, 159
Bradfield, R. (1927). *Proc. First Internal. Cong. Soil Sci.* **4**, 858
Hissink, D. J. (1925). *Trans. Faraday Soc.* **20**, 560
Holfman, T. H. and Gonder (1925). *Colloid. Sym. Monograph* **2**, 225
Loeb, J. (1922). *Protein*, p. 40 : McGraw-Hill
Mattson, S. (1935). *Soil. Sci.* **39**, 745
Pierre, W. H. (1931). *Soil Sci.* **31**, 183
Sen, A. T. (1941). *Indian J. agric. Sci.* **11** 614—6
Puri. A. N. and Uppal, H. L. (1939). *Soil. Sci.* **47**, 245

STUDIES ON LATERITE AND RED SOILS OF INDIA

V. THE SILICA/SESQUIOXIDE RATIO OF THE CLAY FRACTION

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OBSERVATIONS as to laterization of rock *in situ* in different parts of the humid tropics have been well summarized by Robinson [1932]. In general the observations were that the minerals in the rock are converted into a yellowish white flaky material surrounding the unweathered rock in concentric layers. If conditions such as water movements are favourable for the removal of iron, the composition of the laterite approaches that of a low grade bauxite ; otherwise, iron accumulates in the crevices formerly occupied by the basic minerals from which it is derived and cements the whole into a characteristic orange-red vesicular rock.

It is clear from the above that laterization is associated with the liberation of free iron and alumina in the weathered material. Soil chemists have tried to utilize this fact in their effort to define soils of a lateritic type. The presence of free alumina in their opinion indicates that the weathering of rocks under laterizing conditions proceeds a stage further than the kaolinite formation, the lowest proportion of silica in combination with alumina. Since weathering is mainly confined to that part of the soil known as the weathering complex or clay, Martin and Doyne [1927] advance the idea that the silica/alumina (molecular) ratio of the clay fraction of a soil below that of kaolinite (2·0) indicates the presence of uncombined alumina. Such soils according to them may be regarded as lateritic. Furthermore, soils whose silica/alumina ratios fall below 1·33 may be regarded as typical laterites.

Some workers prefer to use the silica/sesquioxide ratio to silica/alumina ratio for characterizing laterite, but Martin and Doyne [1927] do not consider iron to be an essential constituent of laterite soils ; on the contrary the inclusion of iron in the ratio will, according to them, make many ferruginous soils formed under temperate climate come under the lateritic group.

Robinson [1928], on the other hand, considers iron to be an essential constituent of soil clay and that its presence in the clay should not be regarded as accidental. In a private communication to one of the authors (A. T. S.) he stressed that silica/sesquioxide ratios should be used as criteria to define Indian laterites. Robinson [1932] thinks that Martin and Doyne's exclusive choice of alumina for characterizing purposes is too narrow, while Hardy and Follett-Smith [1931] believe that iron oxides play an important part in determining soil properties, such as cohesion and the power of absorbing phosphates.

TABLE I

Percentages of SiO_2, Al_2O_3 in the clay fraction of supposed laterite soils of India

Soils arranged according to the increasing order of silica/alumina (molecular) ratio]

Serial No.	Lab. No. of soil	Soil from	Per cent SiO_2	Per cent Al_2O_3	Per cent Fe_2O_3	Silica/ alumina	Silica/ sesqui-oxide
1	30	Madras . . .	30·09	39·72	8·18	1·31	1·16
2	60	Burma . . .	31·95	38·74	10·84	1·40	1·19
3	64	Do. . . .	31·75	36·85	9·53	1·74	1·25
4	58	Bombay . .	33·30	33·62	15·88	1·69	1·30
5	34	Madras . . .	33·47	33·57	16·20	1·70	1·30
6	32	Do. . . .	35·92	35·93	13·82	1·70	1·37
7	80	Assam . . .	38·59	32·75	12·09	2·00	1·62
8	88	Assam . . .	32·34	27·07	10·52	2·03	1·63
9	24	C. P. . . .	35·47	28·00	23·83	2·15	1·39
10	20	Burma . . .	40·03	31·56	10·99	2·15	1·75
11	70	Bihar . . .	42·44	31·98	10·52	2·25	1·86
12	98	Bengal . . .	45·30	31·87	6·03	2·41	2·15
13	72	Orissa . . .	43·26	30·23	10·99	2·43	1·98
14	78	Assam . . .	43·77	30·20	12·73	2·50	1·95
15	44	Bengal . . .	44·51	30·02	9·52	2·52	2·10
16	1	Bihar . . .	38·71	25·87	17·81	2·54	1·77
17	38	Bengal . . .	43·95	28·89	14·62	2·59	1·96
18	56	Bombay . .	41·99	27·35	16·99	2·60	1·87
19	74	Orissa . . .	45·28	28·11	11·91	2·73	2·16
20	90	Burma . . .	45·82	28·45	9·90	2·73	2·24
21	26	Madras . . .	45·34	26·75	15·08	2·88	2·12

Martin and Doyne [1930] later recognize that some soils (not necessarily tropical) containing much iron have low silica/sesquioxide ratios and a comparatively high silica/alumina ratio and that such soils may have properties similar to those of lateritic soils. They prefer, however, to class these soils as ' pseudo-lateritic ' rather than lateritic since there is no evidence of extremely advance stage of weathering (including presence of free alumina) of which laterite is the outcome.

They recognize further that free alumina may sometimes be present in a part of the clay fraction, while the ratio of silica to alumina in the rest of the clay is sufficiently high to bring up the ratio of the whole fraction to over 2·0. This is a stage which must frequently be found in soils which are gradually laterized. So they modify their previous view and state that a silica/alumina ratio of 2·2 or 2·3 might be regarded provisionally as a suitable upper limit for these soils. According to Shantz and Marbut [1923] such soils are much more abundant than laterite itself.

It should be emphasized that Martin and Doyne's classification is based on the data gathered in the examination of soils in Sierra Leonne. It remains to be seen whether soils with similar silica/alumina ratios (in the clay) from other parts of humid tropics (e.g. India) correspond to those of Sierra Leone. The investigation reported here was carried out with this idea in view.

Soils used in this part have been described fully in part I (Table I) of this series. It may be mentioned here that all the dark-coloured soils became deep red after removal of the organic matter.

In Table I the percentages of silica, alumina, iron oxides of the clay fractions of these soils are given. The table shows that of the 21 soils examined, the clay fractions of only six have silica/alumina (molecular) ratio below 2·0, while those of two soils have the ratio at about 2·0 and the rest have ratios ranging from 2·15 to 2·88. Half the number of soils examined, therefore, do not fall within the class of lateritic or pseudo-lateritic soils as distinguished by Martin and Doyne. On the other hand all the soils with the exception of only five have silica/ sesquioxide ratios in their clay fraction below 2·0. Consequently in the case of 16 soils at least the silica/ sesquioxide ratio indicates the presence of free ferric hydroxide and, by inference, aluminium hydroxide [Robinson, 1932].

DETERMINATION OF FREE ALUMINIUM AND IRON HYDROXIDES

Hardy [1931] has developed a method of identification and approximate estimation of sesquioxide components in soils by adsorption of alizarin. The principle underlying the method lies in the fact that iron hydroxide in the fresh state readily adsorbs this dye while aluminium hydroxide does not. On ignition, iron hydroxide loses the capacity to adsorb, while aluminium hydroxide readily takes up the dye. So, by noting the amount of dye adsorbed by the soil before and after ignition, an approximate idea of the amount of free iron and aluminium hydroxides present in the soil may be obtained. Although the method is not very accurate, it is good as a rough test. In Table II the free alumina and iron oxides present in the soils are given.

TABLE II

Percentages of free iron and aluminium hydroxides present in Indian laterite soils

(Oven-dry basis)

Soils arranged according to the increasing order of silica/alumina (molecular) ratio of their clay fractions as in Table I

Serial No.	Lab. No. of soil	Free Al_2O_3 per cent	Free Fe_2O_3 per cent	Total free sesquioxide per cent	Silica/ alumina	Silica/ sesquioxides
1	30	23·5	5·0	28·5	1·31	1·16
2	60	22·4	4·7	27·1	1·40	1·19
3	64	9·2	5·0	14·2	1·47	1·25
4	58	11·7	3·8	15·5	1·69	1·30
5	34	23·2	4·5	27·8	1·70	1·30
6	32	19.3	3·1	22·4	1·70	1·37
7	80	4·6	4·1	8·7	2·00	1·62
8	88	9·3	1·6	10·9	2·03	1·63
9	24	6·8	2·8	9·6	2·15	1·63
10	20	3·3	1·1	4·4	2·15	1·76
11	70	3·4	1·4	4·8	2·25	1·86
12	98	0·76	1·09	1·85	2·41	2·15
13	72	3·2	1·2	4·4	2·43	1·98
14	78	5·3	0·82	6·1	2·50	1·59
15	44	1·1	0·76	1·9	2·52	2·10
16	1	2·4	3·6	6·0	2·54	1·77
17	38	4·1	1·4	5·5	2·59	1·96
18	56	7·4	1·1	8·5	2·60	1·87
19	74	3·1	2·6	5·7	2·73	2·16
20	90	4·5	1·6	6·1	2·73	2·24
21	26	3·3	0.66	3·9	2·88	2·12

It will be seen from Table II that the amount of total free sesquioxdes is high in soils whose clay fractions have silica/alumina ratios below 2·0. Nevertheless free sesquioxides are also present and in some cases amount to 8-10 per cent of the whole soil, whose clay fraction has silica/alumina ratio distinctly above 2·0, e.g. soils 56 and 24 (serial Nos. 18 and 9 respectively). Most of the above soils can, however, be included into the lateritic group if silica/sesquioxide ratio below 2·0 is taken instead as the upper limit. Still, there are some soils, e.g. soils 74 and 90 (serial Nos. 19 and 20), whose clay fractions have silica/sesquioxide ratio above 2·0, yet they contain 5-6 per cent of free sesquioxides. It appears therefore that if the presence of free hydrated aluminium oxide or free sesquioxides is taken to indicate laterization, nothing but a broad distinction can be made by the use of either silica/alumina or silica/sesquioxide ratio below 2·0. The reason, as has already been stated before, is that free aluminium or sesquioxides may sometimes be present in a part of the clay fraction, while the ratio of silica/alumina or silica/sesquioxide in the rest of the clay is sufficiently high to bring up the ratio of the whole fraction to over 2·0. Further it may be also, as Eden [1929] has obtained evidence with some tea soils of Ceylon, that the ratios higher than 2·0 for soils containing free sesquioxides are due to the presence of finely divided silica (quartz) derived from the parent rock in the clay fraction, a probability not very unlikely in view of silty nature of most of the so-called Indian laterite soils. A third possibility may also be recognized. A considerable proportion of free sesquioxides may occur in the coarser fractions of the soils. They may retain the property of dye adsorption and will thus be detected, while their absence from the clay fraction will tend to increase the silica/alumina or silica/sesquioxide ratios. For example in the soil No. 24 from Raipur, C. P., which contains 17 per cent clay, the amount of Al_2O_3 in the clay as per cent of the whole soil is 4·2 (calculated from Table I), whereas the percentage of free alumina present in that soil is 6·8 (Table II). In other words even admitting the unlikely possibility that all the alumina in the clay fraction exists uncombined with silica, there will be still roughly half as much alumina present in free state in the coarser fractions of the soil and is detected by the alizarin dye.

Finally, it is quite probable that the evidence of laterization may be partially destroyed by resilication in some soils. The possibility of resilication in soils derived from unconsolidated sediments due to concomitant precipitation of silicic acid from river waters has been stressed by Robinson [1928]. The investigations of Mattson [1931] on iso-eletric precipitates demonstrate how such precipitation may take place. Consequently, it is quite possible that resilication has taken place in soils, such as the Dacca soils (soil 98, serial No. 12, Table II) which are alluvial laterite soils. Furthermore, Harrison [1910] says that formation of laterite may occur both in well-drained mountain areas and badly-drained low-lying areas but where the rainfall is intermittent or the drainage poor, laterite may be resilicated by capillary rise of ground water containining silica or silicates in solution, or by a change in the ground water level. The gibbsite previously formed is converted into a hydrated aluminium silicate, principally crystaline kaolin, and the laterite is changed into a red soil.

Considering all these facts, the authors are of opinion that any attempt to evolve precise definition of laterite soils from the silica/alumina or silica/sesquioxide ratio of the clay fraction is not likely to meet with success. The attempt may even mislead the issue. The maximum that can be said in favour of these ratios is that these may serve as convenient checks, but other means must be sought to define a laterite soil. The work of Hardy and

Follett-Smith [1931] shows that the profile of the soil should be examined in every case and in the next part an examination of the soil profiles of some of the laterite areas in India is reported.

SUMMARY

1. Silica/alumina and silica/sesquioxides molecular ratios of the clay fractions and the amount of free aluminium and iron hydroxides by the adsorption of alizarin (Hardy's method) in 21 so-called Indian laterite soils have been determined.

2. The clay fraction of only six soils have silica/alumina ratios below 2·0, while those of the remaining soils have the ratios ranging from 2·0 to 2·8. On the other hand, the clay fractions of 16 soils have silica/sesquioxide ratios below 2·0.

3. The six soils whose clay fractions have silica/alumina ratios below 2·0 contain also fairly large amounts of free alumina and total free sesquioxides. Free sesquioxides are also present and in some cases amount to 8-10 per cent of the whole soil whose clay fraction has silica/alumina ratio distinctly above 2·0.

4. The possibilities of the presence of free sesquioxides in soils whose clay fractions have silica/alumina or silica/sesquioxide ratio above 2·0 as well as the masking of evidence of laterization due to resilication in soils have been discussed.

5. It is stressed that any attempt to evolve precise definition of laterite soils from the silica/alumina or silica/sesquioxide ratio of the clay fraction is not likely to meet with success. The attempt may even mislead the issue.

ACKNOWLEDGEMENTS

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REFERENCES

Eden, T. (1929). *Tea Res. Inst. Ceylon Bull.* **4**, 8
Hardy, F. (1931). *J. agric. Sci.* **21**, 150
Hardy, F. and Follett-Smith, R. R. (1931). *J. agric. Sci.* **21**, 739
Harrison, J. B. (1910). *Geol. Mag.* **7**, 439
Martin, F. J. and Doyne, H. C. (1927). *J. agric. Sci.* **17**, 530
————————(1930). *J. agric. Sci.* **20**, 135
Mattson, S. (1931). *Soil Sci.* **31**, 57
Robinson, G. W. (1928). *Nature* **121**, 902
————————(1932). *Soils* : Thomas Murby & Co.
Robinson, W. O. (1932). *Tech. Com. Imp. Bur. Soil Sci. No.* **24**, 15

SEMI-COMMERCIAL TRIALS ON THE MANUFACTURE OF CANNED PEARS (WILLIAMS') AND PEAR JAM AT LYALLPUR

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(With Plate XXXV and one text-figure)

PEARS of very good quality are extensively grown in the Kulu valley (Punjab). The area under this crop can be greatly extended if some satisfactory outlet could be found for this fruit. At present, however, the price realized from sale of fresh fruit in normal years is not enough even to cover its picking and packing charges, as the fruit growers, due to lack of proper storage facilities and the high cost of transport, are unable to market their fresh fruit profitably outside the valley. As a result of this, the best quality fruit sells in the valley at 8 as. to Re. 1 per maund (82 lb.). For the benefit of growers and prospective manufacturers, any suitable outlet for such fruit is, therefore, worthy of consideration.

With this end in view, the present work was undertaken and it embodies detailed results of semi-commercial trials on the canning of pears (Williams' or Bartlett) and pear jam, caried out in a small cannery in the Fruit Section at Lyallpur for a period of three years (1937-39). The cannery with the necessary equipment was installed in 1936 by a special grant given by the Government of India out of Rural Reconstruction Funds for semi-commercial trials on the manufacture of various kinds of fruit and vegetable products.

The principal aim of the investigation was to collect complete data on the cost of production of canned pears. All cull fruit was utilized for making jam and its cost of production was also worked out. It may, however, be mentioned that at present there is not much demand for pear jam in the Indian market.

MATERIAL

Preliminary experiments on the canning of pears conducted under the Fruit and Vegetable Preservation Scheme, Punjab, financed jointly by the Imperial Council of Agricultural Research and the Punjab Government had shown that out of the five varieties of pears, viz. Williams', Marie Louise, Beurre Blanc, Doyenné Diette and Napoleon, Williams' was the best canner. In later experiments, pressure tests [Allen, 1929 ; Magness *et al.*, 1929] carried out on Williams' variety indicated that these pears when picked at 13-14 lb,

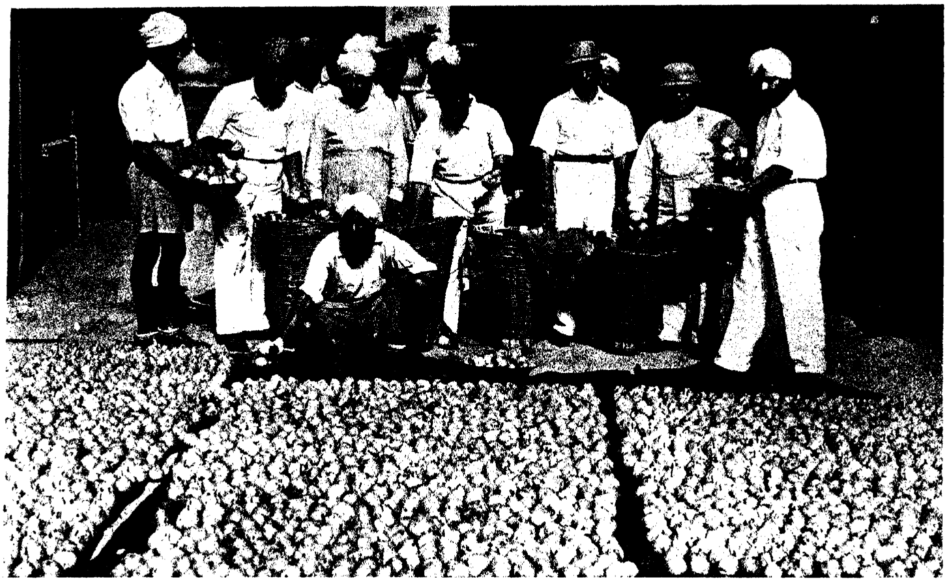

FIG. 1. Arrival and unpacking of pears at Lyallpur

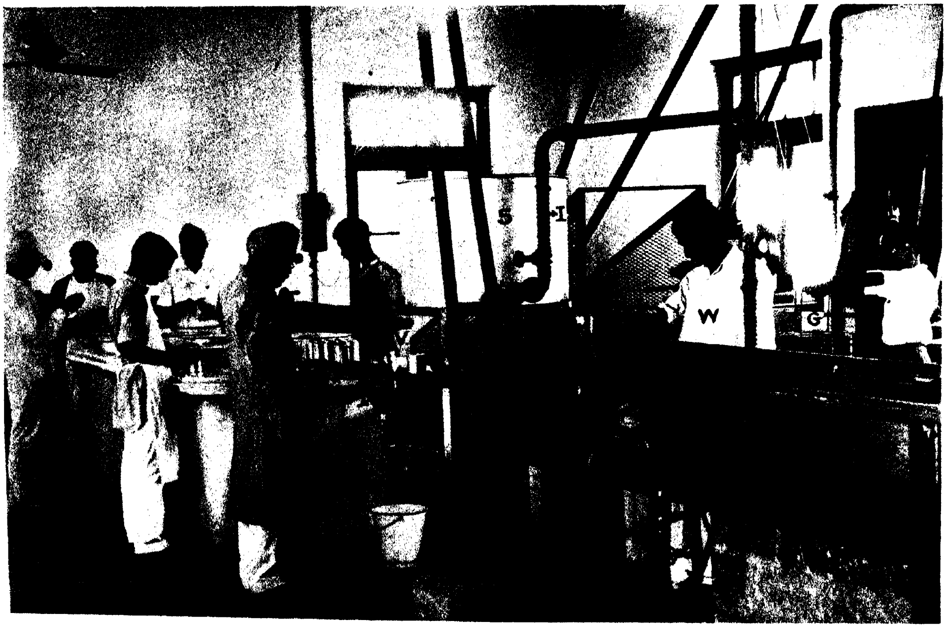

FIG. 2. Canning of pears as conducted in the cannery

[S=Syruper or the brine tank ; I=Steam inlet to S ; V=Trigger valve for pouring syrup ; C=Can being filled with syrup ; R=Set of can rails ; T=Syrup collecting tundish ; W=Workman taking out the can from the exhauster ; G=Crate for the cans]

pressure and subsequently transported to Lyallpur and stored at 60°-70°F'.' gave the best quality product. On the basis of these results, Williams-pear was picked at Kulu and was subsequently transported to Lyallpur where it was stored until ready for canning.

CONSIGNMENTS OF PEARS FOR SEMI-COMMERCIAL TRIALS

Ordinarily pears from Kulu are sent out in small baskets of 9 lb. capacity costing an anna each. This method when applied to large consignments is naturally very expensive. Only a small quantity of pears during 1937 were got in this manner, while a major portion was received in cone-shaped baskets called *kiltas* (Plate XXXV, fig. 1). Each *kilta* has a capacity of about 60-80 lb. and costs two annas each. It was found that fruit packed in these baskets arrived in excellent condition and, consequently, during subsequent years, this was the only method employed for getting the fruit.

Kulu town is situated about 370 miles from Lyallpur. The 80-mile road from Jogindernagar which is the nearest railway station from Kulu is through a dangerous hilly tract and offers considerable transport difficulties. On this line, freight charges are almost double the normal and this makes it rather difficult for the development of any fruit industry at Kulu. In order to avoid unnecessary injury to fruit and to cut down transport charges to some extent, fruit for our experiment was sent out from Kulu in motor lorries.

In 1937, 64 maunds (Table I) of pears were received in two lots. Much difficulty was experienced in storing the fruit at the right temperature as no suitable arrangements were available. The fruit had, therefore, to be stored at ordinary summer room-temperature ranging from 72° to 108° F. which resulted in shrivelling of the fruit. Only 28 maunds of fruit was found fit for canning and 796 A 2 cans were prepared. Fifteen maunds of shrivelled fruit was used for making 573 lb. of jam (Tables II and III).

TABLE I

Cost of pears as transported from Kulu to Lyallpur

1 Year	2 Quantity of pears	3 Total price of pears at Kulu	4 Price per md. at Kulu	5 Cost of packing material (baskets, wrappers)	6 Labour charges for picking, packing, etc.	7 Transportation charges from Kulu to Lyallpur	8 Octroi duty at Lyallpur	9 Total cost at Lyallpur	10 Cost per md. at Lyallpur
	Mds. sr	Rs. A.	Rs. A. P.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A. P.
1937 .	64 5	57 0	0 14 3	55 0	22 15	205 0	8 0	347 15	5 6 10
1938 .	71 0	53 4	0 11 11	46 12	20 4	225 0	11 2	356 6	5 0 4
1939 .	30 24	17 9 (including picking charges)	0 9 2 (including picking charges)	19 5	6 4 (Packing only)	85 2	4 6	132 10	4 5 4

In 1938, 71 maunds of pears were obtained, a portion of which was canned immediately on arrival as it had attained the desired ripeness. Hard and green fruit was stored at 60°-70° F. in the air-lock of a cold storage plant installed during the course of the year. A fair proportion of the consignment

TABLE II

*Cost of production of canned pears**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	Size of can	Quantity of pears	Cost of pears at Lyallpur	Quantity of sugar	Rate of sugar per md. (82 lb.)	Total cost of sugar	Quantity of salt	Cost of salt	Cost of coal	Cost of container	Cost of labour, labels, excluding supervision charges	Total No. of cans prepared	Total cost	Cost per unit†	Percentage of total fruit (Table 1) used for canning
		Mds. sr.	Rs. A.	lb.	Rs. A.	Rs. A.	Md. Sr.	Rs. A.	Rs. A.	Rs. A.	Rs. A.		Rs. A.	Rs. A. P.	
1937 . .	A 2	28 0	151 15	336	9 0	36 14	0 16	2 0	15 0	76 1	20 15	796	302 13	0 6 1	43·7
1938 . .	A 2½	21 28	108 15	347¼	10 4	43 6	0 6	0 12	10 8	70 5	21 2	530	255 0	0 7 8	30·6
1939 . .	A 2	8 5	35 3	156½	12 0	22 14	0 3	0 6	7 4	36 10	9 11	366	112 0	0 4 11	26·5

*Cost per tin in 1937 (first year of trial) is high because a good deal of the fruit shrivelled and rotted due to absence of appropriate storage facilities.

TABLE III

*Cost of production of pear jam**

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	Quantity of pears	Cost of pears at Lyallpur	Quantity of sugar	Rate of sugar per md. (82 lb.)	Cost of sugar	Quantity of citric acid	Cost of citric acid	Cost of coal	Labour excluding supervision charges	Total cost	Jam prepared	Cost per lb.	Remarks	Percentage of total fruit (Table I) used for jam making
	Mds. sr.	Rs. A.	lb.	Rs. A.	Rs. A.	lb.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	lb.	A. P.		
1937	15 0	81 6	406	9 0	44 9	3¾	5 0	7 0	14 0	152 15	573	4 3	Cost of containers may be added to this	23·4
1938	24 5	121 2	742¼	10 4	92 12	1¼	1 14	10 8	15 10	241 14	1,070	3 7	Do.	34·0

*In working out the cost of production fruit that went waste in transport or otherwise has not been taken into consideration. The data given are based on the actual amount of fruit used in these trials.

reached in over-ripe condition and this was utilized for making jam. The total amount of fruit used for canning was 21 maunds 28 seers (530 A 2½ cans) and for jam 24 maunds 5 seers (1070 lb. jam) (Tables II and III). About 4-5 maunds of fruit rotted during transport and storage, while the rest was utilized for other experiments.

During 1939, the pear crop in Kulu, due to lack of timely rains, was of poor quality. Out of the 30·6 maunds of pears obtained, only 8 maunds were used for canning (366 A 2 cans). About 9·5 maunds were used for cold storage experiments, 2·5 maunds rotted during transit and storage, and the rest of the fruit (being of inferior quality) was either sold locally or used for other experimental work.

CANNERY

The canning experiments were conducted in a cannery istalled in 1936 by a special grant of Rs. 15,000 from the Government of India, Rural Development Funds. The canning unit was supplied by Messrs Mather and Platt of Calcutta at a cost of Rs. 2,400 and it essentially consists of one water exhaust, one syrup tank of about 50 gallons capacity, one cooling and one cooking tank (Fig. 1). Apart from these, there is a reforming machine, a flanger and a double seamer which were purchased from Messrs Metal Box Co. Ltd., Calcutta, at a cost of Rs. 1,400 (Plate XXXV, fig. 2). To minimize the cost of containers, these were purchased flat and were later reformed.

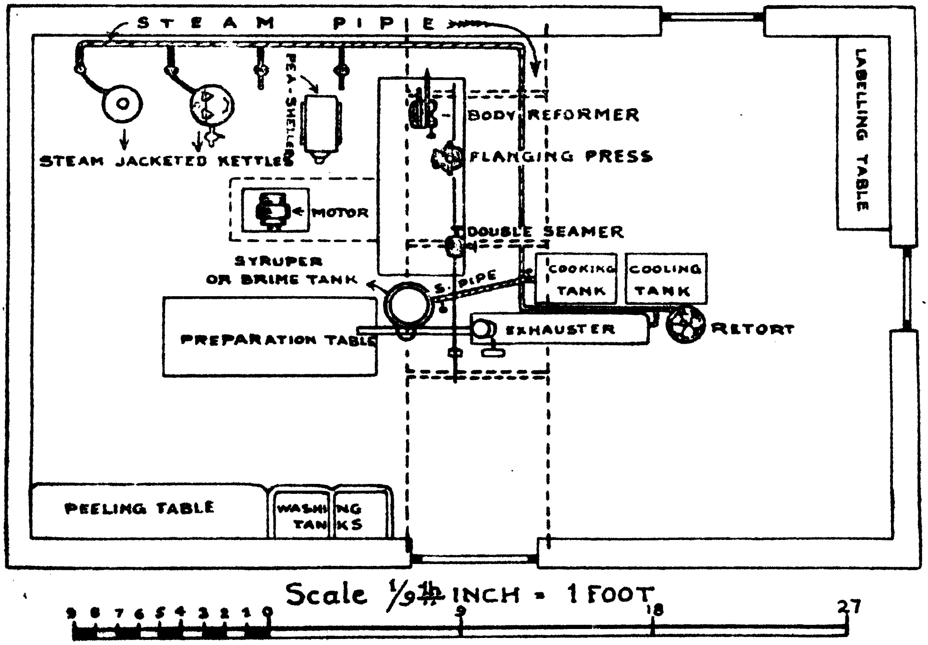

Fig. 1. Lay-out plan of cannery

EXPERIMENTS

Canning

Fruit fit for canning was first washed in running water, peeled, cut into halves, cored, graded and packed in either A2 or A2½ cans using cane sugar syrup of 40° brix. Only fancy grade fruit was packed. The A2 and A2½ cans were given a process of 20 and 25 mins. respectively, in boiling water and were immediately cooled. Due to high summer temperature, it was found necessary to use ice for the cooling tank. Finished cans were kept in a basement store where the temperature ranges from 70° F. to 95°F. during summer months.

Jam making

Fruit which was unfit for canning was peeled, cored and was either cubed or sliced before boiling in a steam-jacketed kettle with a small quantity of water—when necessary—to soften the pulp. Pure cane sugar was added at the rate of ¾ lb. per pound of pulp and the boiling finished at 221° F. which corresponds to 66 per cent sugar in the finished product. 2-3¾ ounces of citric acid dissolved in a small amount of water was added to every 100 lb. of pulp towards the finish of the boiling. Jam was packed hot (180°-190°F.) in glass jars and cans.

Samples of canned pears and pear jam were sent to Messrs J. Lyons and Co., Ltd. London, who reported as follows (Detailed report on the analyses of canned pears and pear jam is reproduced in the appendix) :—

1. *Canned pears.*—' This is a satisfactory sample of canned pears comparing well with the canned pears usually available in this country '.
2. *Pear jam.*—' This is a satisfactory sample of canned pear jam, but it is not likely to be of interest in England as pear jams have very little sale '.

COST OF PRODUCTION

Details regarding picking, packing, transport, etc. of fruit from Kulu are given in Table I. It will be seen that the cost of fruit actually delivered at Lyallpur worked out to nearly 6-8 times the original purchase price at Kulu, transport charges alone being responsible for a 4-5 fold increase in it. The price of fruit at Kulu varied from 9 annas 2 pies to 14 annas 3 pies per maund, whereas at Lyallpur, the cost per maund came to about Rs. 4-5-4 to Rs. 5-6-10. Further, it will be noted that during 1938-39 incidental expenses were considerably reduced as a result of the experience gained in 1937.

Data for the cost of production of canned pears are given in Table II. It will be seen that the cost of production of an A2 can in 1937 and 1939 worked out at six annas one pie and four annas 11 pies respectively, while in 1938, the cost of an A 2½ can came to seven annas eight pies. It will be seen that the number of cans got per maund of fruit in 1939 was nearly one and a half times that in 1937. This is because the entire lot of peeled fruit was found fit for canning during 1939 while in 1937, due to prolonged storage at high temperature, most of it went waste.

From Table III it will be seen that the cost of jam came to four annas six pies and three annas seven pies per lb. in 1937 and 1938 respectively, the higher cost in 1937 being due to the poor quality of the fruit. The cost of containers has not been included. Jam in these trials was partly packed in one lb. jam jars, each costing two annas five pies and partly in A2 cans costing one anna nine pies each.

In the end, it may be pointed out that a canning factory situated near the fruit-producing area, such as Jogindarnagar, Palampur or even Pathankote, will considerably reduce the cost of production. Further, installation of a plant in a cool place will dispense with storage difficulties which is an important factor to be considered in the manufacture of canned pears.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Government of India for a special grant for the erection of the cannery, to the Punjab Government for providing funds for carrying out these semi-commercial trials and to the Imperial Council of Agricultural Research for providing facilities for standardizing the methods of preparation of canned pears and pear jam. Their thanks are also due to Dr G. S. Siddappa and Mr G. L. Tandon for the assistance rendered in collecting the data given.

SUMMARY

1. Details of picking, packing and transportation of Williams' pears from Kulu to Lyallpur and their disposal have been given.

2. The cost of production of canned pears and pear jam has been worked out. The price of pears at Kulu varied from nine annas two pies to 14 annas 3 pies per maund which, when transported to Lyallpur (situated at a distance of of about 370 miles from Kulu), came to about Rs. 4-5-4 to Rs. 5-6-10 per maund, that is, nearly 6-8 times the original price. The price of an A 2 can varies from 4 annas 11 pies to 6 annas one pie and of an A 2½ can is about 7 annas 8 pies. The cost of jam per lb. ranged from 3 annas 7 pies to 4 annas 6 pies. In working out the cost of production, supervision and depreciation charges have not been included.

3. Establishment of a cannery near the centre of production, such as Jogindarnagar or Palampur or even Pathankote, is recommended as it is considered that this will lead to considerable reduction in the cost of production.

REFERENCES

Allen, F. W. (1929). *Calif. Agric. Expt. Sta. Bull.* **470**

Magness, J. R. *et al.* (1929). *U. S. Dept. Agric. Washington, D. C. Tech. Bull.* **140**

APPENDIX

REPORT OF MESSRS J. LYONS & CO., LTD., LONDON

CANNED PEARS

Wrapping.—The can was wrapped in glacine-type paper

Label.—Pears ; Canned
Fruit Products Laboratories
Punjab Agricultural Department, Lyallpur

Description of container.—Cylindrical tinned can with lapped seam and sanitary seals

Condition of tin.—Slightly stained
Weight of contents.—1 lb. 5 oz.
Weight of pears (drained).—12 oz.
Weight of juice.—9 oz.
Ratio of pears to juice.—1·33 : 1
Condition of pears.—Colour : Slightly darker than usual but satisfactory
Flavour : Satisfactory
Consistency : Satisfactory

Analysis.—Refractometric :	solid content	26·7
Preservatives	sulphur dioxide	not found
	Benzoic acid	,, ,,
	Boric acid	,, ,,
	Salicylic acid	,, ,,
Tin		90 parts per million.

Microscopical examination.—Total count on sugar malt extract agar : less than 10 per gram.

Culture on 3 per cent agar : No mould in 20 c.c.

Summary and general criticism.—This is a satisfactory sample of canned pears, comparing well with the canned pears usually available in this country.

CANNED PEAR JAM

Wrapping.—The can was wrapped in a glacine-type paper
Label.—Pears jam
Fruit Products Laboratories
Punjab Agricultural Department, Lyallpur
Description of container.—Cylindrical tinned can, lacquered inside, with lapped seam and sanitary seals
Condition of container.—Excellent, the lacquer being almost unmarked
Weight of contents.—1 lb. 9 oz.
Description of contents.—Flavour : Normal
Colour : Normal
Consistency : Firm and glutinous. The jam contains some small pieces of pear but most of the fruit is in a pulped condition.

Analysis.—Refractometric :	Solids content	72·8 per cent
Artificial colour		not found
Preservatives	Boric acid	,, ,,
	Benzoid acid	,, ,,
	Salicylic acid	,, ,,
	Sulphur dioxide	,, ,,
Tin		,, ,,

Microscopical examination.—Total count on sugar malt extract agar : Less than 10 per gram. Culture in yeast mixture : Sterile.

Summary and general criticism.—This is a satisfactory sample of canned pear jam, but it is not likely to be of interest in England, as pear jam has very little sale.

RESEARCH NOTE

INHERITANCE OF ALTERNATE AND OPPOSITE ARRANGEMENT OF LEAVES IN *SESAMUM INDICUM* DC

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AMONG the 34 unit species of sesamum isolated in the Punjab by Ali Mohammad and Alam [1933], some types have an alternate arrangement of leaves on their plants while in others the arrangement of leaves is opposite. In several inter-varietal crosses made a few years ago with the object of synthesizing better types than those already existing, the arrangement of leaves on the stem was found to be a heritable character. The mode of inheritance of this character does not appear to have been studied by previous workers and the observations recorded here are, therefore, being reported for the first time.

EXPERIMENTAL RESULTS

The F_1 progenies of crosses involving alternate and opposite-leaved varieties of sesamum were invariably observed to have alternate arrangement of leaves, showing thereby the dominance of this character over the opposite condition.

In F_2 the segregation of the allelomorphic pair 'alternate and opposite leaves' was studied in eight crosses. The observed and expected frequencies of each phenotypic class in these crosses (Table I) harmonize well with the 3 : 1 segregation, the fit of observed frequencies of various phenotypic classes with those expected according to monohybrid ratio being statistically good in every case. These data, therefore, lead to the conclusion that there is only a monogenic difference between the alternate and opposite-leaved characters in sesamum.

In F_3 the splitting of alternate and opposite-leaved characters was studied in a large number of families of the various crosses under study. According to expectations, all the cultures whose F_2 parents had opposite leaves, bred true to that character, confirming thereby the recessiveness of the opposite-leaved character as outlined above. Out of the alternate-leaved cultures grown in F_3, the number of those which bred true or splitted further like the F_1 plants and the segregation in the latter are shown in Table II.

TABLE I

Data with regard to the segregation of alternate and opposite leaves in F_2 of different sesamum crosses

Cross	Character of parental types with regard to the arrangement of leaves on the plant		Segregation in F_2		Deviation / P. E.	Fit good or not
			Alternate leaved	Opposite leaved		
T22 × T 5A . .	T22 = Alternate .	Observed . .	195	74		
	T5A = Opposite .	Expected on 3 : 1 ratio	201·75	67·25	1·43	Good
T 5A × T22 . .	Do. .	Observed . .	133	49		
		Expected on 3 : 1 ratio	136·5	45·5	0·90	Good
T 15 × T 5A .	T15 = Alternate . T5A = Opposite	Observed . .	172	60	0·30	Good
		Expected on 3 : 1 ratio	174	58		
T 5A × T 15 . .	Do. .	Observed . .	299	96	0·48	Good
		Expected on 3 : 1 ratio	296·25	98·75		
T 18 × T 5A . .	T18 = Alternate .	Observed . .	67	15	2·11	Good
	T5A = Opposite .	Expected on 3 : 1 ratio	61·5	20·5		
T 5A × T 18 . .	Do. .	Observed . .	408	117	2·1	Good
		Expected on 3 : 1 ratio	393·75	131·25		
T 22 × T 26 . .	T22 = Alternate .	Observed . .	59	14	1·72	Good
	T26 = Opposite .	Expected on 3 : 1 ratio	54·75	18·25		
T 26 × T 22 . .	Do.	Observed . .	62	11		
		Expected on 3 : 1 ratio	54·75	18·25	2·9	Good

TABLE II

Observed and expected frequencies of true-breeding and splitting alternate-leaved cultures in F_3 and the segregation of the latter with regard to alternate and opposite arrangement of leaves

Cross	Number of alternate leaved cultures		Segregation in splitting cultures		Deviation/P. E.	Fit good or not
	Breeding true	Splitting like F_1 plants	Alternate leaved plants	Opposite leaved plants		
T 22 × T 5A Observed	7	9	312	100	0·52	Good
Expected on 3: 1 ratio .	5·3	10·7	309	103		
T 15 × T 5A Observed	4	7	465	157	0·27	Good
Expected on 3 : 1 ratio .	3·7	7·3	465	155		
T 5A × T 15 Observed	9	14	2259	695	2·80	Good
Expected on 3 : 1 ratio .	7·6	15·3	2215·5	738·5		
T 18 × T 5A Observed	3	4	145	46	0·44	Good
Expected on 3 : 1 ratio .	2·3	4·7	143·25	47·75		
T 5A × T 18 Observed	7	15	1918	586	2·77	Good
Expected on 3 : 1 ratio .	7·3	14·6	1878	626		
T 22 × T 26 Observed	5	7	279	85	0·71	Good
Expected on 3 : 1 ratio .	4	8	273	91		
T 26 × T 22 Observed	6	8	240	72	0·78	Good
Expected on 3 : 1 ratio .	4·6	9·3	234	78		

CONCLUSION

The F_2 and F_3 data presented above establish conclusively that alternate and opposite arrangement of leaves in sesamum are heritable characters, the former being dominant over the latter and the difference between the two being monofactorial.

REFERENCE

Ali Mohammad and Alam. Z. (1933). *Indian J. agric. Sci.* 3, 897-911

GIPD—3 S—838 IC of AR—27-8-41—750.

ORIGINAL ARTICLES

THE GENUS *FUSARIUM*

VI. A RECENT ATTEMPT AT MASS REVISION

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RECENTLY there appeared a brief paper by Snyder and Hansen [1940] which is certain to attract a great deal of attention by plant pathologists and mycologists interested in the important genus, *Fusarium*, the world over. In it they formally convert all the species, varieties or physiologic forms of *Fusarium* in the section Elegans, totalling 41 in number, into one single species, *Fusarium oxysporium* Schlecht., the description of which they emend to agree with that of the section Elegans given by Wollenweber [1913]. The species they regard as being divided into physiologic forms differing merely in pathogenicity and capable of identification by virtue of the diseases they cause. It is claimed that an analysis of a large number of single-spore isolates has shown the capacity of Elegans *Fusaria* to produce both sporodochial and non-sporodochial types of variants and relatively large or small macroconidia in the progeny from a single conidium. This, they say, at once makes untenable the present basis for division of the section into the three sub-sections and by the same token invalidates the species in them. The species *F. oxysporum* (in the emended sense) can, they add, be determined readily on morphological criteria, and the biologic forms by pathogenicity tests. The system is said to be readily usable and to give the plant pathologist a clearer concept of the nature of the fungi with which he is dealing. It is claimed that the taxonomic system proposed merely modified Wollenweber's system, into the main framework of which (i.e. Wollenweber's grouping in sections) it fits well.

Such mass revision is unusual in any group of plants, and on this account, coupled with the tremendous economic importance of this group of fungi which cause the majority of wilt diseases of economic crops, taxonomists and pathologists alike will naturally wish to investigate the validity of the changes. There is no doubt that if found valid and acceptable the proposals will be adopted with enthusiasm, for it will then unquestionably bring to an end all the confusion that has existed hitherto in the taxonomy of the group. The problem can be best tackled by first studying the way in which the section Elegans and its related sections, Liseola and Lateritium, were erected and revised, and the present conception concerning them.

ORIGIN OF THE SECTIONS OF *FUSARIUM* AND THEIR PRESENT STATUS

Wollenweber [1913] started dividing the genus *Fusarium* into sections 'in order to unite species having related characters, the most important of which is a uniform shape of conidia'. He erected the sections Martiella, Elegans, Discolor, Gibbosum, Roseum and Ventricosum. His description of the section Elegans is as follows :—

> 'All species have scattered, ellipsoidal, unicellular conidia, averaging 5-12 × 2-3·5μ in size. Many species have also sporodochia with a sclerotial base and pionnotes. The sickle-shaped conidia have the form of the Elegans type (Figs. E, F, S), mostly 3-septate, but also 4 and 5-septate. The average size differs according to the species, the majority having 3-septate conidia, 25-40 × 3-4·5μ, while the 4-septate are somewhat larger, and the 5-septate average 40-50 × 3-4·5μ. Conidia in masses, mostly salmon-coloured, but in some species brownish-white, in others brilliant orange. Conidiophores verticillately branched in sporodochia (Fig. V). Chlamydospores ellipsoidal, terminal and intercalated (Fig. T, V), the unicellular ones being 5-10μ, the 1-septate ones up to 12μ Ascerigous state unknown.
>
> Species in the section are : *Fusarium oxysporum* (Schlecht.), *F. tracheiphilum* Smith, *F. vasinfectum* (Atk.), *F. lycopersici* Sacc., *F. niveum* Smith, *F. redolens* n. sp., *F. orthoceras* App. and Wr., *F. conglutinans* n. sp., notes on which follow'.

Wollenweber regarded the presence of a wine-red colour on rice as a striking character of typical species of the section Elegans, though he mentioned it only incidentally, and not in the description of the section, and the new. species *F. conglutinans* was distinguished from other members by lack of this colour.

Wollenweber illustrated the difficulty of basing taxonomic decisions merely on studies of exsiccatae, when we have no criterion of the degree of maturity of the organs investigated. Maire separated species of *Hypomyces* with obtuse ascospores from Plowright's *Hypomyces* and established the new genus *Nectriopsis*, the ascospores of which have an apiculate end. This was due merely to the fact that Maire was studying, in some cases, immature ascospores.

Wollenweber [1917] divided the section Elegans into three sub-sections, but did not describe them. They contained the following species :—

SUB-SECTION ORTHOCERA

- *F. citrinum* Wr.
- *F. orthoceras* App. et Wr.
- *F. orthoceras* App. et Wr. var. *albidoviolaceum* (Dasz.) Wr.
- *F. orthoceras* App. et Wr. var. *longuis* (Sherb.) Wr.
- *F. asclerotium* (Sherb.) Wr.
- *F. angustum* Sherb.

SUB-SECTION CONSTRICTUM

- *F. moniliforme* Sheld.
- *F. bulbigenum* Cke. et Mass.
- *F. batatatis* Wr.

SUB-SECTION OXYSPORUM (CYANOSTROMA)

- *F. tracheiphilum* (E. F. Smith) Wr.
- *F. vasinfectum* Atk.
- *F. vasinfectum* Atk. var. *inodoratum* Wr.

F. oxysporum Schlecht
F. oxysporum Schlecht emend. Wr.
F. hyperoxysporum Wr.
F. sclerotioides Sherb.
F. aurantiacum (Lk.) Sacc.
F. niveum E. F. Smith.

SUB-SECTION OXYSPORUM (PALLENS)

F. blasticola Rostrup
F. euoxysporum Wr.
F. zonatum (Sherb.) Wr.
F. lycopersici (Sacc.) Wr.
F. redolens Wr.

Thus the section Elegans (with its three sub-sections and two 'series') which originally contained eight species, was expanded to include 23 species and varieties. These have since undergone much change in position [Wollenweber and Reinking, 1935]. The species *F. moniliforme* Sheld. is now recognized as the type species of the important section Liseola. Four members of the sub-section Oxysporum have been transferred to Constrictum.

At the same time Wollenweber [1917] erected the section Lateritium, giving a Latin description, which may be translated as follows :—

> 'Mycelium white, rose, yellow, but never carmine, aerial to immersed, intercallary chlamydospores often, but terminal ones always, deficient : sclerotia nodular, rough, often of a dark blue colour, erumpent from a spreading stroma. Conidia brick-coloured, of the same form as species of the section Elegans, in tubercular sporodochia, in pionnotes or scattered in the aerial mycelium. Many species are now recognized as the conidial stages of *Gibberellae* '.

Fusarium uncinatum Wr. from *Cajanus indicus* (=*C. cajan*), Pusa India, was described, and it was mentioned that chlamydospores are absent. The following species were included in the section Lateritium :—

F. larvarum Fuck.
F. uncinatum Wr. (=*F. udum* Butl. [Padwick, 1940,2])
F. salicis Fuck.
F. salicis Fuck. var. *pallens* Wr.
F. lateritium Nees.
F. pyrochroum (Desm.) Sacc.
F. urticearum (Cda.) Sacc.
F. fructigenum Fries.
F. fructigenum Fr. var. *majus* Wr.
F. sarcochroum (Desm.) Sacc.
F. robiniae Pass.

Thus, the section was made to comprise 11 species and varieties (with imperfect stages of certain species of *Gibberella*), of which only two still stand as good species of this section, four having come to be regarded as synonymous with *F. lateritium* Nees, three as varieties of that species, and one (*F. robiniae* Pass.) having been found synonymous with *F. sarcochroum*. *Fusarium larvarum* Fuck. has since been transferred to the section Arachnites, although that section was already existing at the time.

In the following year Wollenweber [1918] gave a Latin description of the section Elegans, with reference to his original description published in 1913, together with very brief Latin descriptions of the sub-sections Orthocera and Oxysporum, which may be translated as follows :—

'Microconidia mostly simple, 5-12 × 2-3.5μ : macroconidia free, in tubercularia-like sporodochia or running together in pionnotes, straight in some species, more or less falcate in others, more curved at the apices than at the middle, pointed to constricted on both sides, more or less pedicellate at the base. Azure blue sclerotia formed in many species. This section, which otherwise strongly resembles Lateritium, differs in its abundant production of microconidia and terminal chlamydospores.

α. Sub-section Orthocera Wr.

Sporodochia imperfect and frequently quite lacking, microconidia typically present. Length of the conidia nine to twelve times their width.

Examples : *F. orthoceras* App. et Wr., *F. citrinum* Wr.

β Sub-section Oxysporum Wr.

Sporodochia typically present. Stroma more or less erumpent and warty, sclerotial. Length of the conidia eight to ten times their width.

A series Cyanostroma

Stroma more or less erumpent and tinted azure blue

Examples : *F. tracheiphilum* (Erw. Sm.) Wr., *F. vasinfectum* Atk., *F. oxysporum* Schlecht., *F. sclerotioides* Sherb., *F. aurantiacum* (Lk.) Sacc.

A series Pallens.

Stroma pale and gelatinous, rarely erumpent ; sporodochia readily coalescing.

Examples : *F. euoxysporum* Wr., *F. zonatum* (Sherb.) Wr., *F. redolens* Wr.'

Wollenweber, Sherbakoff, Reinking, Johann and Bailey [1925] recorded the results of carefully considered investigations on the genus *Fusarium*. They recognized the existence of 'borderline strains' between sections. They pointed out that the production of the 'norm'—that is, generally speaking, macroconidia—is necessary for proper identification, but that microconidia may have definite characters which aid in the determination of the section and in exceptional cases may even lead to the identification of the species. They point out that colours of the conidia and colour of the aerial mycelium and stroma are further reliable characters for taxonomy, e.g. rose to wine-red or lilac is typical of many species of section Elegans, carmine red of Discolor, Roseum and Sporotrichiella, and citric or sulphuric yellow of the sub-section Neesiola. It is of especial interest to us that chlamydospores, by their presence or absence, indicate the border of certain groups with similar macroconidia, notably Elegans and Lateritium, while sclerotia may be characteristic for groups, such as Lateritium.

Wollenweber, Sherbakoff, Reinking, Johann and Bailey described the new section Liseola, which (translated) is as follows :—

'Section Liseola (Syn. Constrictum Wr. pro parte subs. Elegantis ; Moniliforme Sherb.) microconidia more or less methodically arranged in chains, fusoid to ovoid, macronidia of the form and colour of Lateritium, free or in sporodochia or pionnotes : chlamydospores absent : stroma violet. Conidial states of *Gibberella* of the section Lisea (Sacc.)'.

From the key to sections given by these authors we also get a much clearer conception of the section Elegans than was given by Wollenweber in 1913. Thus, we learn that the microconidia are not in chains (one reason why the Liseola *Fusaria* were separated from this section) ; that the conidial walls are thin, and that the conidial masses are brownish to salmon on a vinaceous to lilac, but never green, stroma, all important characters distinguishing Elegans from Martiella. We also learn that conidia of Elegans, Liseola and Lateritium are practically indistinguishable in their form, thinness of walls, and colour, and that the only important differences are in microconidia and chlamydospores. Lateritium has no typical microconidia, Liseola has them arranged in chains, Elegans has them singly or in false heads; Liseola and Lateritium have no chlamydospores. Elegans has them both terminal and intercallary.

At about this time Wollenweber and Reinking [1925] indicated the changes in value which had come to be accepted for various characters. They pointed out that the general type of macroconidia, at one time regarded as the most important character in the taxonomy of *Fusaria*, has proved to be of more value when considered in conjunction with other characters, for example the presence of microconidia, chlamydospores, sporodochia and pionnotes. They point out how closely allied are the sections Liseola, Lateritium and Elegans.

The most elaborate description of the various sections of *Fusarium* appears in Wollenweber and Reinking's [1935] book '*Die Fusarien*'. The description of the section Elegans, though more complete than previously given in the articles mentioned above, is altered in only one important aspect; it is mentioned that whereas in some species the macroconidia are long, spindle-needle-shaped, tapering at both ends or slightly constricted, in other cases they are more compact, spindle-sickle-shaped with constricted, and frequently somewhat hooked, apices. These hooked spores are also common in Lateritium, as now mentioned in the description of this section. The terminal chlamydospores are again described as absent in Lateritium, the intercallary ones in the conidia and mycelium as more or less copious. If we see the descriptions of the species, however, we find that in many cases the chlamydospores are entirely lacking, as stated in the key given by Wollenweber *et al.* [1925]. In a later publication, Wollenweber himself [1938] says that chalmydospores do occur terminally on occasions in the fungus *Fusarium lateritium* Nees var. *uncinatum* Wr. From Wollenweber and Reinking's work we furthermore learn that the varieties *minus* and *uncinatum* both produce copious microconidia in the aerial mycelium. Thus, the two sections, Elegans and Lateritrium, remain similar in spore form; the only difference lies in their less frequent production of terminal chlamydospores and of typical microconidia, or rather in the restriction of these to one or two varieties, and in the lack of wine-red colour in the section Lateritium.

The conception of the group Liseola has undergone considerable alteration. Only half of its members have typical chains of microconidia. As in the case of Lateritium and Elegans, some members have distinctly hooked macroconidia (*F. moniliforme* Sheld. var. *anthophilum* (A. Br.) Wr. and *F. lactis* Pir. *et* Rib.) All the species lack chlamydospores, but so, for that matter, do *F. stilboides* Wr. and *F. sarcochroum* (Desm.) Sacc. of Lateritium.

Where now is the dividing line between the three sections, Elegans, Lateritium and Liseola?

OVERLAPPING OF GROUPS

It has been clearly shown that since the sections Elegans, Lateritium, and Liseola were erected, the conception of those three groups has so altered that they are no longer entirely distinct. This does not mean that the descriptions of all these groups of plants are identical, or that all three define exactly the same group of plants. It does mean that they overlap one another to a very marked degree. Since a group of plants is composed of individuals, it means that although there are certain plants which could find a place in only one of the groups, there are others which could conceivably be placed in either of two groups, or even in all three groups.

One of the most difficult fungi to place in its correct group is *Fusarium udum* Butl., the cause of wilt of pigeon-pea and sunn-hemp. Butler [1910] described this fungus in 1910. Later on he [Butler, 1926] regarded it as a synonym of *F. vasinfectum* Atk. Wollenweber [1938] placed it in the section Elegans. I have shown [Padwick, 1940,2], however, that it is the same as *F. lateritium* Nees var. *uncinatum* Wollenweber and that the latter fungus is synonymous with *F. udum*. As to the section to which it belongs, however, I make no pretence at being able to say. *F. lateritium* Nees is the typical species of the section Lateritium and one would presume that a variety of the same species must belong to the same section. When chlamydospores are formed, however, they are frequently terminal not only in isolates obtained by the author from several places in India, but also in Wollenweber's own culture obtained from Baarn. Judged by this criterion, it could not belong to section Lateritium, but must be placed in Elegans. At the same time, there are otherwise identical cultures which so far have not been induced to form typical chlamydospores, and it would seem that these cultures might just as well be placed in section Liseola as section Lateritium, though not in section Elegans. Thus, there are a number of cultures all able to cause piegon-pea wilt, falling into at least two, and perhaps three, sections. I have revived the species *F. udum* Butl., and have concluded that all the isolates causing pigeon-pea wilt and sunn-hemp wilt are one species. Otherwise, we must have almost as many species as isolates—an impossible situation. In fact, this and no other is exactly the conclusion which Snyder and Hansen would have had to reach, had they studied many isolates causing pigeon-pea wilt, and which they did reach by inference having studied only closely related fungi.* But if complete mergence of forms means synonymy, all members of sections Elegans, Lateritium, and perhaps Liseola must be merged into one species. The history of the sections outlined above and their true descriptions, that is to say, their emended descriptions, prove it; *Fusarium udum* Butl. illustrates it. Both Liseola and Lateritium contain forms which are merely imperfect stages of Ascomycetes, species of *Gibberella*. Thus all the members with which we are dealing become synonyms of some *Giberella*.

I have one culture (referred to as 'F 169' by Pawick [1940,2] which causes wilt of sunn-hemp and which is difficult to place in its section, because although belonging to Elegans in other respects it is closer to Martiella in spore shape. Martiella *Fusaria* have Hypomyces for their perithecial form.

There appear to be two flaws in this argument. The first lies in the assumption made by Snyder and Hansen that we can say Wollenweber and his associates are all wrong in their grouping of isolates into species and yet right in their grouping of species into sections. The second lies in the tendency to lose objectivity by concentrating on the potentialities of the species in test-tubes rather than its objective existence in nature.

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* Snyder, from whom an enquiry was made, stated that he had no culture of *F. udum*.

In the genus *Fusarium* we have a jumble of ill-defined cultures, falling roughly into groups, some dintinctly recognizable as belonging to certain groups, others borderline cases. A number of workers, notably Professor W. Brown and his associates at the Imperial College, and now again Snyder and Hansen, have demonstrated the high degree of variability of 'species'. Take any representative of a so-called species, and you can show how atypical descendants resemble adjacent species. Arbitrary lines of demarcation have been selected to divide species from species and section from section. Borderline members of one species resemble borderline members of another; borderline members of one section are not clearly distinct from members on the outside rim of another; and so on all the way up the line. Who can say where *Cephalosporium* ends and *Fusarium* begins? Subramaniam and Chona [1938] have shown how difficult it is to distinguish a boderline *Cephalosporium* from a borderline *Fusarium* of the section Liseola. But we rightly retain *Cephalosporium* as a perfectly good genus.

Fusarium has been shown to be highly variable. To get always an exact determination is at present beyond the ability of mycologists. Many of the cultures which were worked with by Wollenweber were secured from the Centraalbureau voor Schimmelcultures and have been studied by the author in India, and they still retain after several years—after many generations—the characters they were said to possess. The author [Padwick, 1940, I] proposed the conversion of *F. conglutinans* Wr. into a synonym of *F. orthoceras* App. et Wr. but would go no further. Though there may be, and probably are, all the way through the genus and even into related genera, closely linking forms, and though one such form may give rise to descendants difficult to distinguish from a closely related form, there is no evidence so far that any particular form can give rise readily or at all to a more widely separated form. One would like to see evidence, for instance that the culture of *Fusarium bostrycoides* Wr. et Rkg. from Baarn can ever give anything even remotely resembling *Fusarium udum* in the so-called variable characters, colour and spore form.

By converting all the members of the section Elegans into one species, *F. oxysporum*, Snyder and Hansen have undoubtedly simplified enormously the ritual of giving a name to a large number of isolates. They have greatly reduced the possibility of making errors by the simple procedure of being vague. To infer, however, that borderline members of the section can be readily distinguished from borderline members of the sections Lateritium and Liseola, is contrary to the facts. The borders are as indistinct as ever To be consistent, they should have transferred them all to a *Gibberella*. Above all, to emend the description of *F. oxysporum* to that of section Elegans given by Wollenweber [1913] is to ignore all the contributions to our knowledge that have been made since that date. In addition, there is an assumption, implied at least, that pathogenicity is readily determined and constant. As a matter of fact, it is a slow method of identification, and requires exact definitions of environmental conditions and purity of the host rarely attainable even in modern laboratories; as to the constancy of pathogenicity, there is a good deal of evidence to suggest that it is not all we would like it to be. Even as to distinctive specificity there are now grave doubts, for Hansford [1940] claims to have isolated from cotton Elegans ***Fusaria*** with a wide host range. One wonders by what subtle distinction of form or habit Snyder and Hansen, despite their strongly expressed opinions, believe that *F. oxysporum* f. *pisi* should be split up into two 'races', numbers 1 and 2, both causing wilt of *Pisum sativum.* Is it to be the start of a new series of sub-divisions based on undefined pathogenic symptoms, or is it merely a sign of lack of complete faith in their own protestations?

The pity of it all lies in the haste with which Snyder and Hansen have come out with a formal declaration of new names and synonymy. Thanks to the spade-work of Hansen and Smith [1932, 1938], we are probably nearer the correct basis for classification of these forms than ever before. Great possibilities now emerge. We require the stable elements of dual phenomenon, the homotypes, and we want them carefully and thoroughly described to the best of our ability. We want these descriptions based on pathogenicity and geographical distribution, which means that workers all over the world must collect, purify, and describe, and then emend descriptions on the basis of what they have seen, linking their descriptions up, if that is possible, with those of earlier workers, though most of the specimens on which the early descriptions were based are now mouldering piles of dust. These will give us focal points, objective groups upon which we can build our species and base our new deal in taxonomy. We are not ready for that yet, and in any case there is no hurry. When we have got our focal point species adequately described in the new way, with all our modern knowledge of variation, and our modern instruments of statistical measurement, of recording colours, of drawing and photography, we can change names with impunity. Until then, let caution be our watchword. When we eventually make the changes, let us make them with our eyes open and with due consideration of the history of cases and the objectivity of species.

CONCEPT OF A FOCAL POINT SPECIES

Thom [1940], who has spent many years working with Penicillia and Aspergillae, has concluded that they become inextricably involved when large numbers of variants are compared, some of them passing into the Gymnoascus type of fruiting so completely as to make the differentiation of families a quite arbitrary arrangement. Indeed, the classification of groups higher than the species is much more an arbitrary and indecisive matter than that of species, because, while we can with our own eyes see the species as a group capable of perpetuating itself independently of related groups, with an objective existence in geographical position and with clear ecological relationship, available for recording of measurement by all methods of scientific approach, the higher ranks, the families and orders, are something upon which we can only hypothesize as having a phylogenetic relationship susceptible, at least in fungi where palaeontology gives us little guidance, of only rough and ready evolutionary interpretations. With what satisfaction, for instance, can any of us pretend to place the genera *Hypodermella* and *Schizothyrium* in their 'correct' families from an evolutionary point of view? For what reason, other than one of convenience in identification by virtue of method of opening of the hypothecium, do we place the Tryblidiaceae amongst the Phacidiales instead of the Pezizales, to which they would seem to belong equally well ? Between the species of fungi, with their objective existence as concrete living ecological and geographical groups, and the classes, with their distinctive types of sexuality, lie ranks which in some groups are clear cut enough to command common agreement and in other cases are vague, indistinctive and unconvincing.

The work of Hansen and Smith has shown that there exists, in the 'dual phenomenon', something akin to a form of sexuality in many fungi. Akin to it, but yet not sexuality ; akin to chimaera formation, yet not that either. Though probably caryogamy does not take place in the cells resulting from hyphal fusions the effect is similar, namely the production of a number of phenotypes intermediate between the parental homotypes. As far as the taxonomic aspect goes, these intermediate forms are of much the same significance as impure segregating lines in sexually reproducing plants. The tendency to form hyphal fusions and resultant intermediate forms in these 'imperfect' fungi, and the influence of such inevitable intermediate forms on our taxonomic ideas, may receive similar consideration to borderline cases in sexually reproducing kinds of plants. Two quotations from Julian Huxley's introductory chapter to *The New Systematics* [1940] gives us some guidance here. The first of these deals with borderline cases :—

> 'Other border-line cases exist where a chain of forms, each at least sub-specifically nameable, but all connected by intergrading zones of interbreeding, is continued so far that its extremes would immediately be styled distinct species if the intermediates did not exist, and would doubtless behave as such if tested genetically. Carabid beetles provide an excellent example of this. Sometimes nature has actually performed the crucial experiment and range extensions have brought the end forms together in nature, when they do behave as good species in refusing to cross'.

The second deals with hybridization as a single factor criterion :—

> 'As Turrill [1938] has emphasized, the fact that groups may or might show fertile intercrossing when artificially or in other ways secondarily brought together does not disprove their right to be styled species. It is the actual facts of nature, not its every potentiality, with which the systematist has to deal. The fact of their separate existence *qua* self-perpetuating interbreeding groups, together with either a reduction or absence of fertility in inter-crossing, or a certain empirically evaluated degree of morphological or physiological characters, should be taken as the basis of decision.'

In our test-tube work with *Fusaria* we are dealing with the 'every potentiality' of the organisms, or rather, with every potentiality other than the 'actual facts of nature'. We must get down to studying these actual facts by collecting and describing from actual field material, looking for ecological and even geographical species, before we can safely erect a new taxonomy. This is the essence of the recent Presidential Address of Mason [1940] to the British Mycological Society, and it is inescapable.

NOMENCLATURAL CHANGES

On the basis of the reasoning outlined above, the following nomenclatural changes which have been recognized in the papers so far contributed to this series [Padwick, 1940 ; 1,2] are formally set forth with Latin diagnoses where required. It may be noted that it is not proposed to call the *Fusarium* causing wilt of pigeon-pea (*Cajanus cajan*) *F. udum* var. *Cajani* as originally suggested since the original description of *F. udum* included mention of its pathogenicity.

The author is grateful to Dr B.B. Mundkur for suggestions regarding nomenclature and to Dr N. L. Bor of the Forest Research Institute for providing the Latin diagnoses.

Fusarium orthoceras App. et Wr. var. *conglutinans* (Wr.) Padwick, *Indian J. agric. Sci.* **10**, 282 : 1940

Syn. *F. conglutinans* Wr., *Phytopathology* **3**, 30 ; 1913 ; *Ber. Deutsch. bot. Ges.* **31**, 31 : 1913

F. oxysporum Schl. f. *conglutinans* (Wr.) Snyder et Hansen, *Amer. J. Bot.* **27**, 66 : 1940

Morphologice a typo speciei haud distinguendum. Habitat in *Brassica oleacea* Linn. et speciebus cognatis, vitium vasculare in America boreali (U.S.A.) efficiens

Fusarium orthoceras App. *et* Wr. var. *Betae* (Stewart) Padwick, *Indian J. agric. Sci.* **10,** 282 : 1940

Syn. *F. conglutinans* Wr. var. *Betae* Stewart, *Phytopathology* **21**, 67 : 1931

F. oxysporum Schl. f. *Betae* (Stewart) Snyder *et* Hansen, *Amer. J. Bot.* **27**, 66 : 1940

A typo speciei haud distinguendum, vitium plantularum *Betae vulgaris* Linn. in America boreali efficiens.

Fusarium orthoceras App. *et* Wr. var. *Callistephi* (Beach) Padwick, *Indian J. agric. Sci.* **10**, 283 : 1940

Syn. *F. conglutinans* var. *majus* Wr. (*vide* Wollenweber and Reinking, *Die Fusarien*, p. 110)

F. conglutinans Wr. var. *Callistephi* Beach, *Michigan Acad. Sci. Rept.* **10**, 297 : 1918

F. oxysporum Schl. f. *Callistephi* (Beach) Snyder *et* Hansen, *Amer. J. Bot.* **27**, 66 : 1940

A typo speciei morphologice haud distinguendum ; vitium vasculare *Callistephi chinensis* Linn. in plerisque regionibus qua ea planta culta est, efficiens.

Fusarium orthoceras App. et Wr. var. *Ciceri*, var. nov.

A typo speciei morphologice haud distinguendum ; vitium vasculare *Ciceri arietini* Linn. in Delhi Karnalque, India, efficiens.

Culturae in Collectioni Culturarum Typicarum, Imperial Agricultural Research Institute, New Delhi, conditur ; preparationes typicae in Herb. Crypt. Ind. Orient. adsunt.

Fusarium udum Butler, *Mem. Dept. Agric. India* (*Bot. Ser.*) **2**, No. **9**, **54** : 1910

Syn. *F. Butleri* Wr. *Phytopathology* **3**, 38 : 1913

F. uncinatum Wr. *Ann. Mycol.* **15**, 54 : 1917

F. vasinfectum Butler (nec Atk.) pro parte parasitica in radici *Cajani cajan* (L.) Millsp., *Agric. J. India* **21**, 273 : 1926 ; Butler and Bibsy, '*Fungi of India*', *Sci. Monogr. No.* **1**, *Imp. Counc. Agric. Res.* p. 146: 1931.

F. vasinfectum Atk. f. *Cajani* Kulkarni, *Indian J. agric. Sci.* **4,** 994 : 1934

F. lateritium Nees var. *uncinatum* Wr., *Arb. biol. Reich.* (*Berl.*) **22**, **341** : 1938

Syn *F. oxysporum* Schl. f. *udum* (Butler) Snyder and Hansen, *Amer. J. Bot.* **27**, 66 : 1940

Lectotypus in Herb. Crypt. Ind. Orient. Imp. Agric. Res. Institute, New Delhi indicatus est. Culurae in Collectioni Culturarum typicarum, Imp. Agric. Res. Institute, New Delhi, conditur.

Fusarium udum Butler var. *Crotalariae* (Kulkarni) Comb. nov.

Syn. *F. vasinfectum* Atk. pro parte parasitica in radici *Crotalariae junceae* Briant and Martyn, *Trop. Agric., Trin.* **6** 259 : 1929 ; Uppal, Patel and Kamat, *Dept. Agric. Bombay Bull.* **176**, 31 : 1935

F. vasinfectum Atk. f. *Crotalariae* Kulkarni, *Indian J. agric. Sci.* **4**, 994 : 1934

A typo speciei morphologice haud distinguendum ; vitium vasculare *Crotalariae junceae* Linn., haud *Cajani cajan* efficiens. Culturae in Collectioni Culturarum Typicarum Imp. Agric. Res. Institute, New Delhi, conditur ; preparationes in Herb. Crypt. Ind. Orient.

SUMMARY

1. The history of the division of species of *Fusarium* into sections is outlined in relation to sections Elegans, Lateritium and Liseola.

2. It is shown that the present conception of the sections Elegans, Lateritium and Liseola does not agree with the original descriptions ; Elegans was split up into two sections, one retaining the original name and the other being given the new name Liseola.

3. It is as difficult to place borderline members of the three sections in the correct section as it is to identify correctly the species within a section.

4. Snyder and Hansen [1940] assume that, whereas the so-called speices within the section Elegans (and similarly in other sections) must be regarded as one species, the major grouping into sections in Wollenweber's system and the original description of the section Elegans are acceptable. It is shown that this assumption is contrary to the facts as clearly indicated, firstly by careful consideration of the way in which the sections Elegans, Lateritium and Liseola were built up and described, and secondly by the existence of intermediate forms.

5. It is concluded that although the work of Snyder and Hansen [1940] and Hansen and Smith [1932, 1938] must eventually influence classification within the genus, proper revision can only result from the combined efforts of workers in a position to study the various *Fusaria* in their natural habitat. The ultimate classification will have to give sufficient weight to ecological factors and geographical distribution.

6. Nomenclatural changes proposed up to the present are summarized.

REFERENCES

Butler, E. J. (1910). *Mem. Dept. Agric. India (Bot. Ser.)* **2**, No. 9

Hansen. H. N. and Smith, R. E. (1932). *Phytopathology* **22**, 953-64

——————————— (1938). *Mycologia* **30**, 442-55

Hansford, C. G. (1940). *East Africa Agric. J.* **5**, 279-82

Huxley, J. (1940). Towards *the new systematics*, pp. 1-46 : Oxford, Clarendon Press

Mason, E. W. (1940). *Trans. Brit. Mycol. Soc.* **24**, 115-25

Padwick, G. W. (1940,1). *Indian J. agric. Sci.* **10**, 241-84

——————— (1940,2). *Indian J. agric. Sci.* **10**, 863-78

Snyder, W. C. and Hansen. H. N. (1940). *Amer. J. Bot.* **27**, 64-7

Subramaniam, L. S. and Chona, B. L. (1938). *Indian J. agric. Sci.* **8**, 189-90

Thom, C. (1940). *Report of Proceedings, Third International Congress for Microbiology, New York,* **1939**, p. 187 : New York, International Association of Microbiologists 1940 (Seen in *Rev. Appl. Mycol.* **19**, 555-6 : 1940)

Turrill, W. B. (1938). *Biol. Rev.* **13**, 342-73

Wollenweber, H. W. (1913). *Phytopathology* **3**, 24-50

——————— (1917) . *Ann. Mycol. (Berl.)* **15**, 1-56

——————— (1918). *Ber. Deut. Bot. Gesell.* **35**, 732-42

——————— (1938). *Arb. Biol. Reichsanst.* **22**, 339-47

Wollenweber, H. W. and Reinking, O. A. (1925). *Phytopathology* **15**, 155-69

———————————————(1935). *Die Fusarien* : Berlin, Paul Parey

Wollenweber, H. W. ; Sherbackoff, C. D. ; Reinking, O. A. , Johann, Helen and Baile, Alice A. (1925). *J. agric. Res.* **30**, 833-43

STUDIES IN INDIAN CEREAL SMUTS

*II. VARIETAL RESISTANCE OF INDIAN AND OTHER WHEATS TO LOOSE SMUT

BY

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(Received for publication on 14 January 1941)

(With Plate XXXVI and one text-figure)

IN a previous paper [Pal and Mundkur, 1939], we have outlined **the principles** which have been followed in developing cereal varieties **resistant to smuts.** Our efforts to discover varieties of wheat resistant to loose smut are reported in the present communication.

Loose smut of wheat caused by *Ustilago Tritici* (Pers.) Rostrup occurs wherever wheat is grown in India ; the intensity with which it manifests itself and the damage it causes vary with the locality. In the Punjab, Sind and the United Provinces this smut is known to cause considerable damage, and cases are by no means rare where nearly a quarter of the crop has been ruined. Loose smut is an internally seed-borne disease and its control by the external application of fungicidal treatments is not therefore possible. This internal mycelium in its dormant state resists attempts aimed at its destruction but becomes vulnerable to attack after germination. The seed is therefore soaked for four hours in water at a temperature of 26-27°C. and the soaked seed is then transferred to warmer water at 53-54°C., for about ten minutes. Pre-soaking induces the germination of the mycelium in the presence of moisture and the higher temperature kills it. The method is, however, attended by considerable risk as the temperature lethal to the mycelium is only sligthly lower than that which is lethal to the germinating seed itself.

The safest method of controlling loose smut is therefore by the development of varieties that resist the disease, and experience with the Imperial Pusa wheats has shown that among them are varieties which, under field conditions, show considerable resistance. To what extent such resistance is due to genetically determined factors which these varieties possess and how far they are cases of mere disease escape has, however, remained unknown. These investigations were therefore undertaken with a view to obtaining this knowledge.

METHODS

The method employed for infecting wheat heads with a suspension of spores *in vacuo* was the one designed by Moore [1936] and recently re-described by Oort [1939]. The apparatus consists of a glass tube, called the

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*The first article of the series was published in the *Proceedings of the Indian Academy of Sciences* **9**, pp. 267-70 : 1939 inoculation chamber, about 9 inches long and 1·25 inches in diameter. The bottom end of this chamber is fitted with a rubber stopper in which a slit and a hole are made ; a glass tube passes through the hole and is connected by means of rubber tubing to a flask containing a suspension of spores (one gram per litre of water). The heads are inserted into the chamber through the slit and sealed with plasticine to prevent the leakage of air. The top of the chamber is closed with another tightly fitting stopper, through which also passes a glass tube by means of which the inoculation chamber is connected with an exhaust pump. While inserting the wheat heads in the chamber and at the time of manipulating the apparatus, great care has to be exercised so as not to break the culms. The flask containing the spore suspension is placed on the ground, while the inoculation chamber and the exhaust pump are held in the hand. A Mohr pinch-cock, inserted in the rubber tubing leading to the flask, serves to close the access to the flask at will.

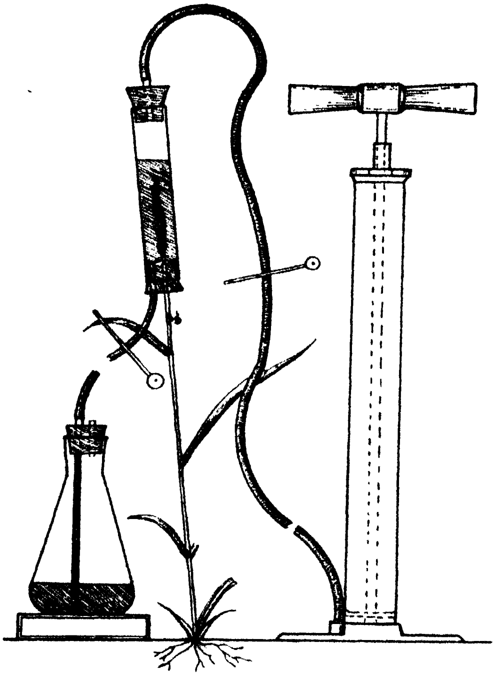


Fig. 1. Moore's method of infecting wheat ears with spores of loose smut

Wheat heads in the mid-anthesis stage are then selected, placed between the slit in the stopper and this stopper inserted in its proper place (Fig. 1). The flask containing the spore suspension is then connected to the inoculation chamber but the pinch-cock is kept closed. The top of the chamber is connected to the exhaust pump and about eight to ten pump-strokes are given to exhaust the chamber. The pinch-cock below is then opened when the spore suspension rushes into the inoculation chamber. A few more strokes are then given and the suspension held in the chamber for a minute, after which the pressure is released. The infected heads are tagged and covered with water-proof paper bags which help in creating a moist atmosphere for some time.

Selecting heads which are of proper maturity and at the correct stage of anthesis takes time, but if two or three heads of the same variety and at the same stage of anthesis are near each other, then all of them can be inserted at the same time into the chamber. About 40–50 heads can be infected in an hour in this manner. The spore suspension must, however, be changed when heads of a different variety have to be infected.

Wheat cultures are sown in single progeny rows, keeping one foot between the plants and 1½ ft. between the rows. This permits free access to the plants without the risk of damaging them, When mature, the infected heads are individually harvested and threshed. Seeds from single heads are sown in separate rows during the next year. At the time of counting the diseased plants, those that show even a single smutted tiller or partially infected heads are classified as diseased. Heads from plants that are absolutely free from smut are utilized for re-infection for the subsequent year's trials.

MATERIALS

The smut used in these experiments was collected at Pusa in January 1937. This collection or its descendants have been used throughout these tests. As physiologic races of loose smut are known to occur in other parts of the world and may occur in India also, care was taken to see that there was no mixture of smuts at any time.

The wheat seeds used in these investigations were from selfed heads and were pure for all the morphological characters.

The first season's trials were conducted at Pusa in 1936-1937 ; the later trials were carried out in the Botanical Section plots at New Delhi.

EXPERIMENTAL

1936-37.—The investigation was started with 40 varieties. They were sown on October 27, 1936, in a secluded plot. The growth of the plants was fair to good. The artificial infection of the heads began on 1st February 1937 and continued for about ten days. Ten to fifteen heads of each variety were infected. Harvesting was done in April, each head being placed in a separate envelope.

1937-38.—The infected seed was sown in single progeny rows on 16th and 17th November 1937. The plants grew quite well and the smut appeared on the 14th February 1938. Plants showing smut were immediately uprooted and a careful record of such plants was kept. The total number of plants per variety, the number that became smutted and per cent smut in each variety are given in Table I.

From the results in Table I it will be noted that the varieties IP 114, IP124 and Federation (all the four stocks) were resistant to the disease, while IP121 was only 0·4 per cent susceptible. Seven varieties, viz. IP 120, IP122, IP123, IP125, Punjab C 499 and Cawnpore 13 had 9·7—20·6 per cent susceptibility, but the rest were highly susceptible. The high percentage of smut infection obtained in these varieties indicated that the method of infecting the seed was very efficient.

Wheat heads from plants that had shown no smut were selected for the 1938-39 trials and 46 additional varieties were included in the tests. These were infected with smut in the usual manner.

1938-39.—Infected seed was sown on 12th and 13th November 1938. The plants made good growth and smut appeared in the first week of February following. As in the previous year, partially and fully attacked plants were uprooted and a record of smutted plants was kept. The results obtained during this season are given in Table II.

TABLE I

Total number of plants per variety, number of smutted plants and percentage of smutted plants in wheat varieties infected in 1936-37

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
1	Imperial Pusa 4	294	68	23·0
2	,, ,, 6	193	47	24·3
3	,, ,, 12	214	125	58·4
4	,, ,, 52	156	48	30·8
5	,, ,, 80-5	131	40	30·5
6	,, ,, 101	198	160	80·8
7	,, ,, 111	157	46	29·2
8	,, ,, 114	156	0	0
9	,, ,, 120	164	16	9·7
10	,, ,, 121	219	1	0·4
11	,, ,, 122	122	24	20·6
12	,, ,, 123	183	21	11·4
13	,, ,, 124	187	0	0
14	,, ,, 125	91	13	14·2
15	,, ,, 126	91	18	19·7
16	Jaipur	107	36	33·6
17	Muzaffarnagar	110	39	35·4
18	Muzaffarpur White	140	79	56·4
19	,, Red	112	36	32·1
20	Lal Kesar Wali	82	27	32·9
21	Punjab 8A	243	34	13·9
22	,, 9D	143	61	45·5
23	,, C409	155	44	28·3
24	,, C499	149	25	16·7
25	,, C518	158	83	52·5
26	,, C591	146	110	75·3
27	Cawnpore 13	256	43	15·1
28	Federation (new stock)	250*	0	0
29	,, (old, red-glumed)	215	0	0
30	,, (old, white-glumed)	115	0	0
31	,, (from Tarnab)	195	0	0
32	Bihar 9	93	60	64·5
33	,, 18	132	56	42·4
34	,, 19	181	49	27·0
35	,, 20	110	71	64·5
36	,, 21	119	62	52·1
37	,, 22	97	52	53·6
38	,, 26	78	48	61·5
39	,, 27	118	74	62·7
40	,, 29	87	31	35·6

TABLE II

Total number of plants per variety, number of smutted plants and percentage of smutted plants in wheat varieties infected in 1937-38

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
1	Imperial Pusa 4	186	172	92·4
2	,, ,, 6	67	63	94·0
3	,, ,, 12	179	169	94·4
4	,, ,, 52	211	194	91·8
5	,, ,, 80-5	191	44	23·0
6	,, ,, 101	81	74	91·3
7	,, ,, 111	127	126	100·0
8	,, ,, 114	141	0	0
9	,, ,, 120	75	0	0
10	,, ,, 121	117	0	0
11	,, ,, 122	121	0	0
12	,, ,, 123	198	181	91·4
13	,, ,, 124	87	0	0
14	,, ,, 125	302	195	64·5
15	,, ,, 126	196	166	84·9
16	Jaipur	72	56	77·8
17	Muzaffarnagar	16	13	81·3
18	Muzaffarpur White	65	60	92·3
19	,, Red	75	60	80·0
20	Lal Kesar Wali	67	59	88·3
21	Punjab 8A	216	201	93·1
22	,, 9D	231	230	100·0
23	,, C409	158	152	96·2
24	,, C499	222	161	72·5

TABLE II—*contd.*

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
25	,, C518	140	135	96·4
26	,, C591	165	165	100·0
27	Cawnpore 13	229	193	84·3
28	Federation (new stock) . . .	149	67	45·0
29	,, (old, red-glumed) . .	119	0	0
30	,, (old, white-glumed) .	42	0	0
31	,, (from Tarnab) . .	127	0	0
32	Bihar 9	42	37	86·5
33	,, 18	82	72	95·1
34	,, 19	72	69	95·8
35	,, 20	75	73	97·6
36	,, 21	76	76	100·0
37	,, 22	59	59	100·0
38	,, 26	48	28	58·3
39	,, 27	75	68	90·6
40	,, 29	38	30	78·8
41	Imperial Pusa 90 . . .	45	33	73·3
42	,, ,, 163-8 . . .	35	0	0
43	,, ,, 163-4 . . .	43	0	0
44	,, ,, 165 . . .	210	0	0
45	111-2-3	63	55	87·3
46	114-2-4	75	65	86·6
47	111-2-6	64	59	92·1
48	111-2-7	68	60	88·2
49	111-2-8	78	29	37·1

TABLE II—*contd.*

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
50	111-2-9	48	34	70·8
51	114-1-47	59	37	62·6
52	114-1-53	48	19	39·6
53	114-3-2	64	47	73·4
54	54-1-1-5	69	62	90·0
55	86-1-1-1	60	58	96·6
56	95-1-1-7	49	0	0
57	54-2-1-1-9	62	54	87·0
58	13-1-5-10E . .	44	3	6·8
59	13-1-5-10L	51	21	41·1
60	64-1-1-10	82	46	56·8
61	3-1-2-6	78	46	58·8
62	CPH 47	80	65	81·5
63	AT 38	48	45	93·6
64	HSW	67	51	76·1
65	Chinese White	56	0	0
66	*T. sphaerococcum*	71	19	26·7
67	Flora	24	0	0
68	Gular	77	62	80·5
69	Geerlying	71	47	66·2
70	Sword	71	0	0
71	Khapli.	73	0	0
72	Garnet.	77	69	89·6
73	Reward	85	31	36·4
74	,, ...	62	30	48·3

TABLE II—*concld.*

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
75	Rajah	52	3	5·7
76	Ranee	68	48	70·7
79	Igachikugo	79	0	0
80	Eshimashiuraki	14	0	0
81	Nawaba	57	10	17·6
82	Ford	38	0	0
83	Dundee	60	0	0
84	Baringa	58	36	62·0
85	Firbank	37	23	62·1
89	Gullen	50	40	80·0
91	Ideal	72	13	18·5
97	Florence	20	0	0

It will again be noted from the results recorded in Table II that the varieties IP114, IP124 and Federation (three stocks) remained highly resistant. Selections for high resistance made in the previous year in the varieties IP 120, IP 121, and IP 122 were also successful, but the other selections proved failures. One stock of Federation which failed to take infection the previous year proved to be a susceptible variety. Among the newly included varieties, IP 163-3, IP163-4, IP165, 95-1-1-7, Chinese white, Flora, Sword, Khapli, Igachikugo, Eshimashiuraki, Ford, Dundee and Florence showed promise. Among others that showed less than 10 per cent susceptibility were 13-1-5-10E and Rajah. The rest were highly susceptible.

Heads from healthy plants were again infected for trial in 1939-40 and three additional varieties were added for the determination of their relative susceptibility to loose smut.

1939-40.—The increase in work made it necessary to exercise discrimination and eliminate certain varieties so as to keep the work within bounds. In making this elimination two things were prominently kept in mind : (1) the degree of susceptibility of a variety, and (2) its economic importance. If a variety was highly susceptible but economically important, it was retained in the hope that further selection within such a variety might furnish resistant individuals. If a variety, on the other hand, was highly resistant or immune but otherwise unimportant or undesirable, it was retained with the object of using it as a parent in hybridization work.

Sowing was done in the third week of November and the plants made good growth. Smut appeared in the second week of February 1940 and smutted plants were uprooted as in previous years. The results are given in Table III.

TABLE III

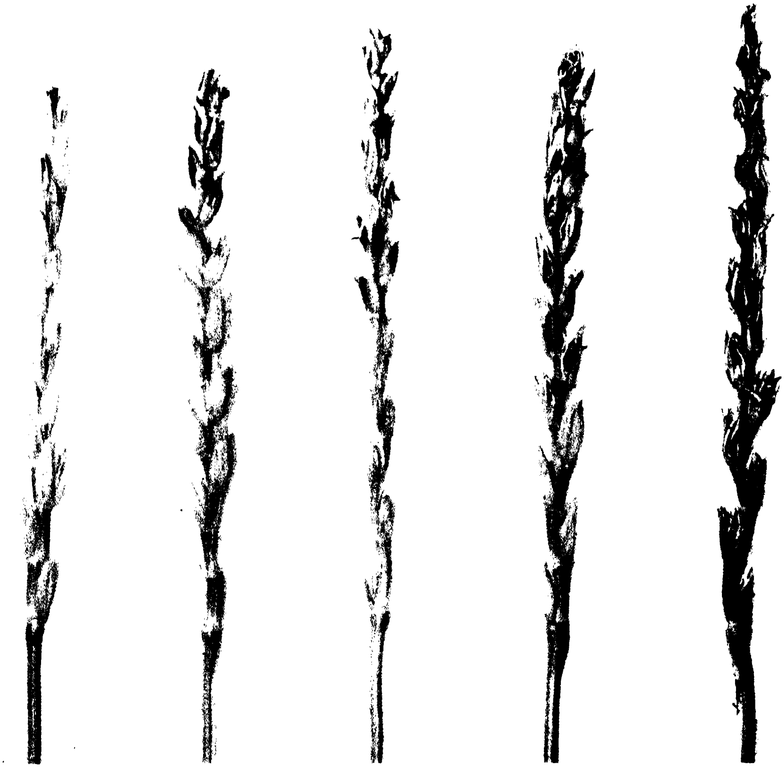
Total number of plants per variety, number of diseased plants and percentage of smutted plants in wheat varieties infected in 1938-39

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
	Varieties immune in previous two seasons			
8	Imperial Pusa 114 . . .	279	0	0
13	,, ,, 124 . . .	342	0	0
29	Federation (old, red-glumed) . .	373	0	0
30	,, (old, white-glumed) .	454	0	0
31	,, (from Tarnab) . .	593	0	0
	Varieties immune in past one season			
44	Imperial Pusa 165 . . .	234	41	17·4
56	95-1-1-7	327	0	0
65	Chinese white	336	4	1·1
67	Flora	222	1	0·4
70	Sword	261	0	0
71	Khapli	183	0	0
78	Free Gallipolli	223	0	0
79	Igachikugo	290	0	0
80	Eshimashiuraki	187	0	0
82	Ford	310	1	3
83	Dundee	317	0	0
97	Florence	307	0	0

TABLE III—*contd.*

Serial No.	Variety	Total No. of plants	Number of smutted plants	Percentage of smutted plants
	Varieties highly resistant in past seasons			
9	Imperial Pusa 120 . . .	210	0	0
10	,, ,, 121 . . .	398	14	4·5
58	13-1-5-10E	328	31	9·4
	Varieties highly susceptible in past seasons			
1	Imperial Pusa 4 . . .	378	257	67·9
4	,, ,, 52 . . .	311	195	62·7
5	,, ,, 80-5 . . .	321	238	74·1
7	,, ,, 111 . . .	309	118	38·1
14	,, ,, 125 . . .	322	48	14·9
21	Punjab 8A	374	184	49·1
25	,, C518	357	237	66·3
27	Cawnpore 13	415	144	33·7
	Newly included varieties			
98	C5271-W1	256	48	18·7
99	Imperial Pusa 100 . . .	268	182	67·9
100	114-1-8	321	0	0
	Controls (fresh seed)			
6	Imperial Pusa 101 . . .	299	271	90·6
26	Punjab C591	288	221	76·7
35	Bihar 20	417	400	96·5

The varieties IP114, IP124 and Federation (three stocks) which were uninfected with loose smut in the first year continued to be so. Imperial Pusa 165 which failed to take infection in 1938-39 showed 17·4 per cent infection. The nature of smut attack in this variety was rather peculiar. Not all the ears in a plant were infected and the ears themselves were only partially attacked. Smutted heads with different degrees of infection are shown in Plate XXXVI. For the present this variety has been classified among the highly resistant and future selections may give completely resistant individuals. Selections made in IP120 and IP121 in 1937-38 continued to maintain their resistance, the former having shown no infection by



Smutted heads of IP 165 wheat showing different degrees of infection

smut in two successive seasons. Most of the others have continued to maintain their resistance likewise. Among the new varieties tested during the year, 114-1-8 seemed to be resistant, while C 5271-W1 may yield resistant selections. The highly susceptible varieties and the controls grown from new seed of these varieties showed, as expected, high susceptibility to smut.

Desirable plants free from smut have, in all the above varieties, been re-infected and 32 additional varieties have been also included for noting their reaction to loose smut. In future it is proposed to include wheat varieties developed by the provincial wheat breeders if time and facilities permit.

DISCUSSION

The four-year trials reported in this paper show that in India, as elsewhere, varieties of wheat highly resistant to, or immune from, loose smut can be successfully bred. Although many of the improved varieties evolved in this country are susceptible, a few of them--notably IP114—are very highly resistant or even immune.

It is interesting to note that these results, carried out under strictly controlled conditions, are in agreement with field experience regarding the resistance or susceptibility of the varieties, wherever such data are available for comparison. Thus, it was already known that under field conditions IP 114 is invariably free from loose smut. A striking example of its freedom from this disease was afforded in 1933-34 at Karnal. The area under this wheat was surrounded every year by a larger area under Punjab 8A which in that and the previous seasons had shown high incidence ; IP114, however, remained uninfected. A few smutted plants observed in the fields were found upon examination to be rogue plants of a different variety. It is also a matter of common knowledge, for example, that Punjab C 591 is highly susceptible to loose smut. In our tests likewise this variety proved to be exceedingly susceptible and we use it as a susceptible ‘ control ’.

A noteworthy fact that needs to be mentioned is that both the immune Indian varieties (and some of the highly resistant ones) are derived from the Australian variety Federation which itself has proved to be immune in these tests. Imperial Pusa 114, for instance, arose as a natural cross in a field of Federation growing at the Imperial Agricultural Research Institute at Pusa. The immune IP124, and the resistant varieties IP120, IP121, IP122 and IP 165 are also of hybrid origin, being the progeny of crosses between Federation and Indian wheat varieties. Evidently genetic factors for high resistance have been transmitted to these hybrids from the Federation parent.

The tests have further indicated that it is possible sometimes to obtain resistant strains by selection within a partially susceptible variety and that varieties which are homozygous for the morphological characters are not necessarily so for smut resistance. The results also show that seasonal factors may influence the degree of infection and a variety which is found to be apparently immune in one season may prove to be slightly or even moderately susceptible in subsequent seasons. In spite of the successful method of infecting wheat heads, varieties which show more than 20 per cent susceptibility should, to be on the safe side, be classified as susceptible, in breeding work.

In any investigation which involves the selection of varieties resistant to a disease, the question of physiological specialization of the causal organism should not be lost sight of. Preliminary work has already shown that such physiologic races of loose smut exist in India and work is in progress to determine their number and distribution.

SUMMARY

Loose smut of wheat caused by *Ustilago Tritici* (Pers.) Rostrup occurs wherever wheat is grown. It can be controlled by the so-called hot water treatment, but this is not free from the hazard of impairing seed viability. The safest and the best method is the growing of smut-resistant varieties.

2. Nearly 100 varieties of wheat have been tested for their reaction to smut. For this purpose each variety was artificially infected using the method devised by Moore.

3. The results show that a few varieties including IP 114 are immune, a large number, including IP 120 and IP 165, are resistant and the majority are susceptible.

4. Selection within several partially susceptible varieties with a view to finding highly resistant or immune segregates was successful. A similar attempt in the case of highly susceptible but economically important varieties proved, however, a failure.

ACKNOWLEDGEMENTS

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REFERENCES

Moore, M. B. (1936). *Phytopathology* **26**, 397-400

Oort, A. J. P. (1939). *Phytopathology* **29**, 717-28

Pal, B. P. and Mundkur, B. B. (1939). *Proc. Indian Acad. Sci.* **9**, 267-70

STUDIES IN INDIAN CEREAL SMUTS

III. VARIETAL RESISTANCE OF INDIAN AND OTHER WHEATS TO FLAG SMUT

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NOT much attention has been given in India to the disease in wheat caused by *Urocystis Tritici* Koernicke and commonly known as flag smut. A short account of it was given by Butler [1918] who first discovered it at Lyallpur in the Punjab. Since that time it has been found to be fairly widespread in the Punjab and the North-West Frontier Province. Plants attacked by flag smut have recently been received from Baluchistan where it is reported to be doing much damage to the wheat crop. Flag smut was found to be fairly common in Southern Afghanistan by Mundkur [1940].

How long the disease has been prevalent in India, is not possible to say with any certainty. The fact that it is not very extensively spread probably indicates recent introduction from some other country, but its absence in the United Provinces, Bihar, Central Provinces, Sind and Bombay may also be due to these areas being relatively warmer in winter than the Punjab and the Frontier Province. Thus even though conditions for the rapid dissemination of the causal organism which is seed-borne exist, favourable conditions for its development do not seem to occur widely, excepting in the restricted areas stated above.

Flag smut can cause considerable damage to the wheat crop when it appears in epidemic proportions, and in places where it has firmly established itself such epiphytotics are not rare. Losses are principally due to decreased yields rather than to the actual deaths of the plants ; the number of badly infected plants and those that die even before the heads have formed is indeed small, but if a large number of culms per plant is infected without actually killing the plants, then the decrease in the yield of grain is quite appreciable. Flag smut has sometimes been found in almost all the plants in a field, but the number of culms affected has been small so that the actual loss of yield was not great. On the other hand, the reverse would have been the case if a heavy infection of the culms had also taken place.

There is, however, another kind of loss which flag smut infection may cause. It has been noted that seed harvested from flag smutted plants is not all viable. Actual germination tests carried out in the Mycological Section with such seed have shown that up to 63·7 per cent of the seed is non-viable and does not germinate. Such seed is much shrivelled and does not possess the bright appearance of good seed.

In the field flag smut manifests itself about four to five weeks after sowing and some time before the heads begin to emerge from the boots. The disease is characterized by the development of more or less straight, yellowish white or grey stripes on the leaves ; these stripes which are the sori of the smut vary from a few mm. in length to frequently the whole length of the leaf. They soon change colour and ultimately turn black and burst, exposing masses of dark-brown spores. Sori may be found on the lower glumes of the flowers and even on the awns. Affected plants are usually stunted, the leaves are rolled and the culms twisted, giving the plants a mis-shapen appearance.

Investigations conducted by McAlpine [1910], Hamblin [1921], Tisdale, Dunegan and Leighty [1923], Yu, Chen and Hwang [1933] and others have shown that flag smut may be disseminated by infected seed, by dung of animals fed on infected wheat hay, and by farm implements used during harvesting and threshing. It is thus both seed- and soil-borne and its control by the use of fungicidal treatments is consequently not always successful. In Illinois, Tisdale, Dunegan and Leighty [1923] reported as a result of an extensive trial that wheat varieties immune, highly resistant or susceptible to flag smut exist. Immune or highly resistant wheats have also been reported from Australia, where the disease is very destructive, by Shelton [1924], Carne and Limbourn [1927], Morwood [1929], Pridham and Dwyer [1930] and others and from China by Yu, Chen and Hwang [1933]. The problem of developing flag-smut resistant wheat varieties either by selection or by hybridization has received considerable attention in the Mycological and Botanical Sections of the Imperial Agricultural Research Institute, New Delhi, during the past three years and the results so far obtained are presented in this paper.

MATERIALS AND METHODS

Spores of *Urocystis Tritici* for infection were collected in April 1937 at Ferozepur, Punjab. The infected leaves were ground into a fine powder which was placed in an excess quantity of water in a large beaker. The mixture was stirred vigorously for a quarter of an hour in order to release the spores from the sori into the water. The mixture was then allowed to settle down when the residue of the leaves floated on top, while the spores settled down below. A large quantity of the spores was collected in this manner, dried thoroughly, and stored in glass vials in the refrigerator. The residue of the leaves was spread in the field where the trials were later to be conducted.

Selfed seed of 97 varieties of wheat was used in these tests. Two days prior to sowing, the seed of each variety was smeared quite thoroughly with the spores and placed in separate petri dishes. Moist sand was then put in the dishes and the dishes were kept in a cool place. On the third day the seed started to germinate. The seedlings were carefully removed, again dipped in a suspension of spores and sown in single progeny rows. The spores themselves had been soaked in water for four days before they were used for smearing the seed. Experiments reported by Noble [1924] have shown that such a pre-soaking treatment of the spores is necessary before they can germinate abundantly.

When flag smut began to manifest itself, the infected plants were uprooted and a careful count of such plants was kept. At the end of the season, five plants that were quite free from flag smut and which showed the typical characters of that variety were selected in each variety.

It will be noted that many wheats were not tested throughout the three years of the experiment. They were discarded not only because of their high susceptibility to flag smut but also because they were of no value from the economic point of view. Some of the susceptible but economically valuable varities were, however, retained in the hope that it would be possible to obtain, within them, less susceptible individuals by further selection.

EXPERIMENTAL

The results obtained during the past three years with the 97 wheat varieties are given in Table I.

TABLE I

Reaction of Indian and other wheats to flag smut

Serial No.	Variety	Percentage of smutted plants		
		1938	1939	1940
1	Imperial Pusa 4 . . .	1·0	0·48	1·5
2	,, ,, 6 . . .	37·0	21·0	. .
3	,, ,, 12 . . .	17·6	9·5	18·1
4	,, ,, 52 . . .	30·2	19·3	35·6
5	,, ,, 80-5 . . .	0	6·2	5·5
6	,, ,, 101 . . .	51·7	15·0	. .
7	,, ,, 111 . . .	0	0	0·5
8	,, ,, 114 . . .	36·2	18·1	24·3
9	,, ,, 120 . . .	34·4	12·4	37·5
10	,, ,, 121 . . .	30·1	15·6	. .
11	,, ,, 122 . . .	29·3	25·0	. .
12	,, ,, 123 . . .	26·7	10·1	. .
13	,, ,, 124 . . .	23·6	6·5	. .
14	,, ,, 125 . . .	42·7	9·1	30·7
15	,, ,, 126 . . .	31·2	17·1	. .
16	Jaipur	25·6	12·0	. .

TABLE I —*contd.*

Serial No.	Variety	Percentage of smutted plants		
		1938	1939	1940
17	Muzaffarnagar	61·6	12·2	..
18	Muzaffarpur White	76·1	21·9	..
19	,, Red	64·6	26·3	..
20	Lal Kesar Wali	6·6	12·8	..
21	Punjab 8A	35·1	7·2	25·0
22	,, 9D	62·5	24·5	..
23	,, C409	44·3	23·6	..
24	,, C499	31·7	9·4	..
25	,, C518	72·7	26·0	38·5
26	,, C591	15·7	8·3	12·5
27	Cawnpore 13	12·4	7·3	17·5
28	Federation (new stock)	18·3	6·4	..
29	,, (old, red-glumed)	64·7	12·8	..
30	,, (old, white-glumed)	41·8	4·2	..
31	,, (from Tarnab)	56·9	3·4	..
32	Bihar 9	46·4	5·6	..
33	,, 18	63·4	23·0	..
34	,, 19	88·6	15·7	..
35	,, 20	67·9	14·6	..
36	,, 21	74·3	22·2	..
37	,, 22	76·9	28·5	..
38	,, 26	84·2	29·0	50·0
39	,, 27	80·5	25·0	..
40	,, 29	84·4	20·9	..
41	Imperial Pusa 90	47·0	25·0	..

TABLE I—*contd.*

Serial No.	Variety	Percentage of smutted plants		
		1938	1939	1940
42	Imperial Pusa 163-3 . . .	17·8	9·7	..
43	,, ,, 163-4 . . .	21·3	12·5	..
44	,, ,, 165 . . .	9·9	10·3	16·1
45	111-2-3	0	0	1·3
46	114-2-4	0	0	1·1
47	111-2-6	0	0	0
48	111-2-7	0	0·3	0·5
49	111-2-8	0	0	0
50	111-2-9	0	0·5	0
51	114-1-47	43·3	10·4	15·6
52	114-1-53	41·6	5·2	13·2
53	114-3-2	6·8	9·6	15·0
54	54-1-1-5	71·3	20·0	..
55	86-1-1-1	42·9	16·0	28·7
56	95-1-1-7	9·9	7·6	..
57	54-2-1-1-9	52·5	23·0	..
58	13-1-5-10E	55·1	3·2	..
59	13-1-5-10L	62·1	13·0	..
60	64-1-1-10	24·5	8·3	..
61	3-1-2-6.	36·4	6·8	..
62	CPH 47	40·9	16·4	..
63	AT 38	49·1	7·4	..
64	HSW	32·5	10·4	..
65	Chinese White	12·7	3·7	..
66	*T. sphaerococcum*	40·5	21·5	..

TABLE I—*contd.*

Serial No.	Variety	Percentage of smutted plants		
		1938	1939	1940
67	Flora	40·3	4·4	..
68	Gular	5·0	3·7	18·0
69	Geerlying	0	0	0
70	Sword	0	3·3	1·8
71	Khapli	4·0	2·0	..
72	Garnet	8·1	13·0	..
73	Reward	1·3	2·0	..
74	,,	0	0·8	..
75	Rajah	8·7	11·4	..
76	Ranee	1·2	0	..
77	Minister	0	2·4	..
78	Free Gallipolli	3·4	17·4	..
79	Igachikugo	0	0	0.4
80	Eshimashiuraki	8·9	7·7	..
81	Nawaba	0	3·7	..
82	Ford	3·3	7·4	..
83	Dundee	0	0	1·2
84	Baringa	0	0	1·8
85	Firbank	9·0	9·0	..
86	Gasta	26·1	34·3	..
87	Genoa	0	0	0·5
88	German	0	0	0
89	Gullen	0	1·6	..
90	Hornblende	0	0	0
91	Ideal	0	10·7	..

TABLE I—*concld.*

Serial No.	Variety	Percentage of smutted plants		
		1938	1939	1940
92	Jonathan	0	6·7	. .
93	Mardi	1·5	0	. .
94	Peragis	0	0	1·3
95	Stockman	0	0	0·5
96	Wandilla	1·6	1·4	. .
97	Florence	0	1·7	. .
98	C5271-W1	. .	2·7	0·4
99	Imperial Pusa 100	. .	3·8	. .
100	114-1-8	. .	14·6	31·8

DISCUSSION

The data given in Table I confirm the findings of other investigators that there are in existence wheat varieties which possess considerable resistance and even immunity to flag smut. The varieties 111-2-6, 111-2-8, 111-2-9, Geerlying, German and Hornblende throughout remained immune from flag smut, while IP 4, IP 111, 11-2-3, 111-2-4, Sword, Igachikugo, Dundee, Baringa, Genoa, Peragis, Florence and C 5271-W1 showed very high resistance, only 0·4-1·8 per cent of the plants succumbing to attack ; infection in these cases was moreover slight, a few culms only being mildly affected. It is possible that these varieties may give immune segregates on further selection.

Up to 76·1 per cent smut was registered in the susceptible varieties in 1937-38, but attack during the succeeding years was not high. The years 1938-39, and 1939-40 were characterized by drought and much less cold in the winter, and both these factors may have operated in keeping down smut attack. These results show in a vivid manner the influence which climatic factors exercise on the appearance of flag smut.

Flag smut is among the few diseases in which physiologic specialization of the causal organism has not yet been reported. But these investigations show that such physiologic races may exist. Pridham and Dwyer [1930] found the varieties Ranee and Florence to be susceptible under Australian conditions, while Baringa and Gullen were classified by them as moderately resistant. In the tests carried out at New Delhi all these four varieties showed only 1-2 per cent infection. The varieties Nawaba and Ford which Pridham and Dwyer [1930] classified as very highly resistant showed 3·7 and 7·4 per cent infection respectively, while their so-called resistant variety, Firbank, showed 9 per cent attack. Presumably therefore the race of flag smut occurring in Australia is different from the one occurring in the Punjab. It is hoped that work now under way will show whether such races exist within India itself.

SUMMARY

1. The flag smut disease of wheat caused by *Urocystis Tritici* is common in parts of the Punjab, the North-West Frontier Province, Baluchistan and also in southern Afghanistan. It is, however, not known from the other wheat-growing regions of India and it is possible that their relatively warmer winters do not favour the development of the disease.

2. Ninety-seven Indian and other varieties were tested over a period of three years for resistance to flag smut. The method used for infecting the seeds is described.

3. Six varieties were completely resistant to flag smut, while 14 varieties including IP 4 and IP 111 showed high resistance. The remaining varieties showed varying degrees of susceptibility.

4. Though physiological specialization in the flag smut fungus has not hitherto been reported, there is reason to suppose that the Indian strain of flag smut used in these studies is different from the one occurring in Australia.

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REFERENCES

Butler, E. J. (1918). *Fungi and disease in plants* : Calcutta

Carne, W. M. and Limbourn, E. J. (1927). *J. Dep. Agric. W. Aust.* 2nd ser. **4**, 4-7

Hamblin, C. O. (1921). *Agric. Gaz. N. S. W.* **32**, 23

McAlpine, D. (1910). *Smuts of Australia* : Melbourne

Morwood, R. B. (1930). *Qd. agric. J.* **33**, 81-8

Mundkur, B. B. (1940). *Kew Bulletin* **7**, 285-8

Noble, R. J. (1924). *J. agric. Res.* **27**, 451-89

Pridham, J. T. and Dwyer, R. E. (1930). *Agric. Gaz. N. S. W.* **41**, 413-5

Shelton, J. P. (1924). *Agric. Gaz. N. S. W.* **35**, 336-8

Tisdale, W. H.; Dunegan, G. S. and Leighty, C. E. (1923). *Bull. Illinois agric. Exp. Sta.* **242**, 511-37

Yu T. F. Chen, H. ; K. and Hwang, L. (1933). *Bull. Coll. Agric. and For. Nanking* **9** (n. s.), 1—18 ; also *Nanking J.* **3**, 217—34 (May 1933)

STUDIES IN INDIAN CEREAL SMUTS

IV. VARIETAL RESISTANCE OF INDIAN AND OTHER OATS TO SMUTS

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THERE are only two fungous diseases of oats which affect the crop rather seriously in India, the covered smut and the loose smut. Of these the covered smut caused by *Ustilago Kolleri* Wille is the more predominant and widespread disease, while the loose smut for which *U. Avenae* (Pers.) Jens. is responsible, is of minor importance and seems to be restricted to certain areas in the Punjab and the United Provinces.

By the application of fungicidal treatments either in the form of dusts or as liquids for steeping the seed, both these smuts have been successfully controlled. Some years ago Mundkur and Khan [1934] showed that the dry spray method of applying formalin to smutty seed completely eliminates the disease. The treatment is now used in several oat-growing sections, its cheapness, the ease with which it can be applied and the complete control which it gives, having rendered it popular.

In the course of the work on breeding better oats by selection and by hybridization, it became apparent that there are varieties which under field conditions are not attacked by smut. Whether this apparent resistance of these varieties is due to genetically determined factors or whether they are mere disease escapes has remained, however, unknown. The result of the efforts made to determine this is reported in the present paper. Owing to its greater importance, the covered smut has naturally received greater attention.

THE CAUSAL ORGANISM OF COVERED SMUT

Usilago Kolleri, the causal organism of covered smut, is externally seed-borne and the disease caused by it is systematic. Reed and Faris [1924] have shown that the infection of the host takes place in the seedling stage, usually through the coleoptile while it is still 2 cm. or less in length. The mycelium very soon makes its way to the embryonic tissues of the oat plant and continues to grow in intimate relation with it for several weeks. At the time of flowering and the development of the ovule, the mycelium grows rapidly and passes into the spore-forming stage, resulting in the replacement of the floral parts by the dusty masses of black spores. In the covered smut the glumes are left somewhat intact, but in the loose smut they are completely destroyed.

Investigations by Reed and Faris [1924] have clearly established that there is a definite connection between certain factors of environment and infection of the host by the covered smut. A temperature of 20°C., a moisture content of about 20 per cent of the water-holding capacity of the soil and neutral reaction have been determined to be most favourable for the initial penetration by the fungus into the host. Once the successful infection has taken place, it is believed that the later development of the smut is not profoundly conditioned by environmental factors.

LONGEVITY OF THE SPORES OF *U. KOLLERI*

The spores of several species of the family Ustilaginaceae are known to live for several years if stored under proper conditions of temperature and relative humidity. Sampson [1928] found viable spores of *U. Kolleri* in a collection which was 5½ years old and Sobel [1933] reports that even 13½ years old spores of this smut are viable. Fischer [1936] noted that the spores of covered smut from herbarium specimens that were four years old had not lost their viability, but older ones, however, had.

Strangely enough and contrary to expectations, under Pusa and New Delhi conditions, the spores of *U. Kolleri* begin to lose their viability very quickly after the fourth month. Mature smutted ears which had been collected during harvest and which had been adequately air-dried, have been stored in a dry place in the laboratory and also in a refrigerator registering about 8°C. throughout the summer ; spores have been screened out of the sori, air-dried, placed in dry test-tubes, sealed, and then placed both in a cool place in the laboratory and in the refrigerator. Attempts have been made to germinate such spores in rain water, in a 2 per cent sucrose solution and a 3 per cent infusion of oat pales, suggested by Diehl [1925]. Negative results have been obtained in all cases in the germination of the spores that were over four months old. Ultimately it was discovered that if smutted ears are wrapped in blotting paper and stored at a temperature of 12°C., the viability of a majority of the spores can be prolonged, at least until sowing time.

What the precise factors are that operate in rendering the spores non-viable has not so far been possible to ascertain. But spores adhering to the pericarp of the stored seed do not seem to lose their viability to an appreciable extent, even though no special storage precautions are taken, for covered smut appears in the fields year after year.

MATERIALS

Spores of covered smut were collected in 1931 from variety BS 1 (now called IP 1) in the Agronomist's plots at Pusa. The spores were 100 per cent viable at the time of collection, but it was later found that 92 per cent of the spores had lost their viability at the time when oats were sown. Only a few infected ears became available, therefore, at harvest time for the subsequent year's trials.

Seeds used in these experiments were from selfed plants and consisted of standard oat varieties, recent selections, promising hybrids and acclimatized exotic varieties. As most of the latter seemed to be highly resistant to covered smut under Pusa conditions, several hybrids between these and the more susceptible Indian oats were made and tested.

METHODS

Prior to sowing, the seeds of all the varieties were dehulled, the investigations by Reed and Faris [1924] and Reed [1924] having shown that this ensures infection by the smut. Four days before the actual date of sowing, the dehulled seeds were wetted and smeared thickly with spores, placed in petri dishes and covered with sand of proper moisture content. The dishes were then placed in an incubator at 20°C. The seedlings were about 2-3 cm. in length on the fourth day when they were transplanted in single progeny rows in the field.

The disease manifested itself as soon as ear formation had started. During harvest, counts of healthy and smutted plants were separately taken and the latter were also uprooted. Representative plants showing the typical characters of the variety were selected from among the healthy plants, for the next year's trials.

The trials were conducted at Pusa from 1932-33 to 1936-37 and at New Delhi from 1937-38 to 1938-39. Because of the failure of the smut spores to germinate consistently, results for the seasons 1933-34, 1934-35 and 1937-38 are not available.

RESULTS OF TESTS WITH COVERED SMUT

The results obtained with the Imperial Pusa and the exotic varieties to determine their reaction to covered smut are given in Table I.

It will be noted from the results recorded in Table I that in 1932-33 almost all the exotic varieties showed little or no infection to covered smut, whereas in 1935-36 only seven exotic varieties, Kinwada S 10, Nebraska 21, Iowar 670, Gopher and Kanota and two Pusa hybrids, viz. I-207-95 and VII-408, showed complete resistance. Only one other variety, Orion, showed substantially less smut, its susceptibility being 7·6 per cent. In 1936-37 the seed of Iowar 670 which had shown immunity from smut did not germinate and was not therefore available for trial, but of the other immune varieties, Kinwada S 10, Nebraska 21, Gopher and IP hybrid I-207-95 were alone free from infection, varieties Kanota and IP hybrid VII-408 showing 0·5 and 0·7 per cent infection, respectively. Selections made in Abundance and Orion oats showed promise, the former being free from disease and the latter having only 3·4 per cent infection. In 1938-39 Abundance, Gopher and IP hybrid VII-408 were free from infection, IP hybrid I-207-95 had 0·7 per cent; the seed of Orion and Kanota did not germinate and the mode of their reaction to smut during that year is not available.

It should be noted that the exotics, Scotch Potato, Abundance, Iowa 103 and Kinwada S10, belonging to the species *Avena sativa* L. are immune, resistant or susceptible to this race of covered smut under Indian conditions. Imperial Pusa 1, 2 and 4 which are Indian varieties belong, however, to *Avena sterilis* L. var. *culta* and are without exception highly susceptible. Hybrids between the various Indian and foreign varieties that have so far been studied and the results of which are given in Table I show a rather wide range of susceptibility and resistance to covered smut and demonstrate that both the *sativa* and the *sterilis* groups from the same crosses are equally susceptible,

TABLE I

Reaction of Indian and exotic oats to covered smut

Identity No.	Variety	Type of base	Percentage reaction to smut				
			Seeds infected without hulling	Seeds infected after hulling			
			1932-33	1932-33	1935-36	1936-37	1938-39
4	Scotch Potato	*Sativa*	0·9	1·2	30·2	12·9	...
5	Abundance	„	1·2	4·3	35·8	0	0
6	Orion	„	0	1·1	7·6	3·4	...
7	Kinwada S 10	„	0	0	0	0	15·4
8	Nebraska 21	„	0	0	0	0	38·0
9	Iowa 103	„	0	0	66·1	44·6	100·0
10	„ 105	„	0	0	...	0	...
11	Iowar 670	„	0	1·0	0	...	...
12	Gopher	„	0	0	0	0	0
13	Kanota	„	0	0	0	0·5	...
1	IP 1	*Sterilis*	19·0	46·7	84·2	49·4	100·0
2	IP 2	„	4·0	54·9	92·0	73·4	98·0
3	IP 4	„	13·4	52·0	73·5	66·8	100·0
38	Cross I* 140-53	*Sterilis*	14·9	53·1	68·0	86·7	91·0
39	361-33	„	10·9	18·5	66·6	...	92·0
41	172-65	„	10·2	20·7	67·1	78·2	100·0
42	271-68	„	2·0	54·6	72·7	64·7	91·0
44	106-50	„	9·5	22·3	65·7	50·9	98·0
45	79-46	„	5·0	55·0	83·3	23·0	...
46	139-87	„	20·3	43·3	65·2	54·7	100·0
48	80-40	„	19·6	18·0	73·6	33·3	100·0
51	14A-35	„	6·1	39·2	60·5	76·8	100·0
53	179-81	„	18·2	32·3	92·5	..	...
58	270-49	„	33·9	29·3	50·6	68·4	94·0
40	36-92	*Sativa*	34·7	17·7	68·5	84·6	...
47	207-95	„	12·2	38·4	0	0	0·7
49	104-24	„	7·9	21·7	54·0	62·5	99·0
50	336-38	„	19·4	35·6	53·1	78·5	100·0
52	84-29	„	4·9	23·8	41·3	78·3	100·0
54	323-51	„	16·1	25·4	60·0	80·1	100·0

*Cross I = Scotch Potato oats × IP 4

TABLE I—*contd.*

Identity No.	Variety	Type of base	Percentage reaction to smut				
			Seeds infected without hulling	Seeds infected after hulling			
			1932-33	1932-33	1935-36	1936-37	1938-39
55	321-73	*Sativa*	3·1	33·8	86·0	...	100·0
56	310-58	,,	6·2	25·0	73·3	86·7	100·0
57	251-32	,,	27·7	22·5	68·0	47·0	100·0
21	Cross II** 109-87	*Sterilis*	24·8	31·8	48·2	49·7	...
22	19-70	,,	41·2	47·1	61·1	71·5	98·0
25	52-87	,,	28·2	32·1	64·5	33·5	94·0
26	93-70	,,	16·7	62·4	61·5	80·9	100·0
27	248-5	,,	37·9	29·0	72·7	52·1	...
31	327-58	,,	28·8	50·0	83·9	54·6	...
32	186-80	,,	38·8	62·0	78·5	...	...
34	162-53	,,	11·6	15·0	75·0	26·1	...
35	8-64	,,	9·3	19·1	62·8	41·6	100·0
18	112-89	*Sativa*	37·7	28·9	38·8	37·0	94·3
17	284-79	,,	40·4	56·6	45·9	46·2	100·0
19	281-83	,,	31·8	54·7	76·5	59·9	98·0
20	151-9	,,	20·2	40·5	70·6	20·5	99·0
23	262-88	,,	8·1	40·8	64·6	43·5	100·0
24	97-84	,,	5·2	42·8	40·0	12·4	97·0
28	Cross II 89-76	*Sativa*	12·4	17·9	63·4	57·1	89·0
29	197-89	,,	21·1	38·4	58·5	60·7	100·0
30	238-27	,,	36·0	37·2	61·0	81·6	100·0
33	93-2	,,	24·0	40·0	80·6	85·7	...
36	308-88	,,	6·6	31·6	63·5	54·5	100·0
37	97-80	,,	38·5	35·4	60·0	18·3	...
16	Cross III† 242-56	,,	29·3	42·3	48·7	49·6	96·3
15	,, IV(*a*)‡ 48-20	,,	10·1	16·8	42·8	43·4	88·0
14	48-74	,,	6·2	53·4	42·0	7·0	76·7
59	,, VII††194	,,	...	...	46·2	0	...
60	408	,,	...	...	0	0·7	0

**Cross II =Scotch Potato oats × IP 2

†Cross III =Abundance × IP 4

‡Cross IV(*a*) =Iowa 103 × IP 1

††Cross VII =IP 4 × Kinwada S 10

showing that there is no linkage between smut-resistance and the *sativa* or *sterilis* type of base.

It will be noted that in 1938-39, the amount of smut in the susceptible varieties and even in those that had shown in previous years an increased resistance to smut was rather high. Two causes can be assigned to this : (1) a new physiologic race of the smut was used and, (2) the environmental factors at New Delhi were more favourable to smut attack. Results obtained by Coffman *et al.* [1931] demonstrate that differences in the reaction of host varieties to the different physiologic races might give different results in the same oat cross from inoculum of different forms and that seasonal and place variations in covered smut may modify apparent segregation. While environmental factors may, therefore, have influenced infection, the possibility of a mixture of physiologic races cannot entirely be ruled out, for though every precaution was taken against this, it is possible that a mixing up may have happened because of the difficulty in obtaining viable spores.

The immune and the highly resistant varieties are now being multiplied in the Botanical Section, and they will be distributed in areas where covered smut occurs in epiphytotic proportions, if they are otherwise found suitable.

INVESTIGATIONS ON LOOSE SMUT

Less attention has been given to this smut, as it occurs rather rarely. In 1928-29, however, an investigation was carried out to see how the varieties developed at Pusa compared with the one cultivated at Lyallpur in their reaction to a collection of loose smut collected at the latter place. It must be stated that no difficulty was experienced in keeping the spores of this smut viable. This investigation was carried out at Pusa and the results obtained are recorded in Table II.

TABLE II

Reaction of Pusa and Lyallpur varieties of oats to loose smut in 1928-29

Treatment of seed	Percentage of smutted plants			
	BS 1 (IP 1)	BS 2 (IP 2)	Pusa Farm seed	Lyallpur seed
Uninfected seed sown dry	0	0·7	0	7·6
Seed soaked in water for two hours	0·1	11·6	0·4	40·8
Seed soaked in a heavy suspension of spores in water for 2 hours	0·1	14·5	0·5	45·0

It will be observed from the data recorded in this table that Imperial Pusa 1 and Pusa Farm seed were highly resistant to the Lyallpur race of loose smut and that Imperial Pusa 2 is moderately resistant. The Lyallpur variety is, however, very susceptible to the disease.

During the next year, the methods of infection were slightly modified. The results are recorded in Table III.

TABLE III

Per cent smut in IP 1 and Lyallpur oats at Pusa in 1929-30

Method of infection	Per cent smut	
	IP 1	Lyallpur oats
Ordinary seed	0·05	1·3
Ordinary seed soaked in water for 2 hours . . .	0·65	22·5
Seed infected before storing and sown dry . . .	19·41	34·4
Seed infected before storing and sown after soaking in water for 2 hours	66·9	78·1
Seed infected with dry spores before sowing . . .	18·2	25·7
Seed infected before sowing in a suspension of spores in water for 2 hours	51·1	91·3

The data show that the method of pre-treating the seed with viable spores has considerable influence in the occurrence of smut in the resulting crop. For successful infection of seed which has not been hulled, it would appear that infecting it with spores before they are stored away and soaking them in water for about 2 hours before sowing, ensures successful results. But removing the hulls of the seeds, smearing them with the spores and then germinating the seed in moist sand at a favourable temperature is by far the most satisfactory method.

DISCUSSION

Several years' work with the covered smut of oats both at Pusa and at New Delhi has shown that among them are varieties which are homozygous for resistance and susceptibility to this disease. Successful infection both by *U. Kolleri* and *U. Avenae* can be brought about by simple methods ; but the spores of *U. Kolleri*, which are known to keep viable for several years in countries with a temperate climate, lose their vitality under Pusa and Delhi conditions rather rapidly, rendering the task of breeding resistant varieties very difficult.

Physiologic specialization in the oat smuts has been demonstrated by Reed [1924, 1940] who has also given a list of differentials that should be used in their determination. These differential varieties do not, however, grow well under Indian conditions. A descendant of the original collection of the covered smut used in these investigations was therefore sent to Reed in 1935 and he [1940] now reports that that is a new race, to which he has assigned the number 14. It is possible that more than one such race exist in India.

Though cheap and efficient methods of treating oat seed to control both the covered and the loose smuts are available, the task of developing resistant or immune varieties is of great importance in this country. Many of the better yielding and good quality oats in this collection having proved susceptible, it is proposed to test the resistance of other new Imperial Pusa hybrid varieties as time and opportunities permit.

SUMMARY

Both the covered (*Ustilago Kolleri*) and the loose (*Ustilago Avenae*) smut of oats occur in India, but the former is by far the more widely spread disease. Efficient seed treatments to control them are available, but a varying degree of susceptibility to covered smut shown by the oat varieties under trial at Pusa led to these investigations being undertaken to see how far this resistance was due to inherent factors.

While no difficulty was experienced in obtaining viable spores of loose smut at the time of infecting the seed during sowing, it was noted that the spores of covered smut quickly lost their germinating power. If the smutted ears were wrapped, however, in blotting paper and stored in a refrigerator, the spores retained their viability.

Tests with 60 Indian and foreign varieties showed that some of the foreign varieties were immune to covered smut, but others were very highly resistant. None of the Indian varieties were resistant, but among the hybrids between the Indian and the exotic varieties, one proved to be immune to covered smut and another very highly resistant.

Physiologic specialization in Indian oat smuts presumably exists. The race of covered smut used in these studies was determined by Reed to be a new one to which he has assigned the number 14.

ACKNOWLEDGEMENTS

Finally we wish to thank Dr B. P. Pal and Dr G. Watts Padwick for critically reading through the manuscript of this paper and for suggestions. We also wish to express our gratitude to Dr G. M. Reed for determining the physiologic race to which our smut belonged.

REFERENCES

Coffman, F. A., Stanton, T. R., Bayles, B. B., Wiebe, G. A., Smith, R. W. and Tapke V. F. (1931). *J. agric. Res.* **43**, 1085-99

Diehl, O. (1925). *Bot. Arch.* **9**, 146-99

Fischer, G. W. (1936). *Phytopathology* **26**, 1118-27

Mundkur, B. B. and Khan, A. (1934). *Indian J. agric. Sci.* **4**, 899-905

Reed, G. M. (1924). *Amer. J. Bot.* **11**, 483-92

——————(1940). *Amer. J. Bot.* **27**, 135-43

Reed, G. M. and Faris, J. A. (1924). *Amer. J. Bot.* **11**, 579-99

Sampson, K. (1928). *Ann. appl. Biol.* **15**, 586-612

Sobel, M. (1933). *Biologist* **15**, 95-6 (Original not seen)

VARIATION IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

II. VARIATION AMONG SEEDS WITHIN A LOCK*

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(With Plate XXXVII and two text-figures)

THE large amount of variation that is incident in any sample of cotton has been analysed in detail by Turner [1929], who has enumerated the various factors that are responsible for producing the variation. The purpose of the present studies is to enquire into the extent of variation that would be caused by some of the factors enumerated by Turner. The variation of fibre weight with respect to the length of the fibre was studied by Turner and Iyengar [1930] and the variation of other properties with length has been dealt with in another place [Iyengar, 1939]. The present work contains the study of the variation with respect to the position of the seed in the lock, that is, a variation in relation to the proximity or otherwise to the source of food supply within a boll.

Turner [1929] himself has recorded a number of determinations on this point in locks of A 19 and has observed some wide differences. Unfortunately the positions of the seeds in the lock were not made clear. Ramanatha Ayyar and Jagannatha Rao [1930] determined the halo length of seeds in different positions and found distinct variations among them. Sen [1932] working on Punjab cottons observed that the fibre weight per unit length for the apical seed is lowest, whereas fibres from the seeds nearest the base have comparatively higher weights per unit length than the fibres from any other seed in the lock. Armstrong and Bennett [1933] found an increase in mean fibre length from the base of the lock up to the sixth position. It is thus seen that different workers have found definite differences in some of the characters they studied.

The present investigation is divided into two parts ; the first deals with certain seed and lint characters, the second part being devoted to description of the fibre characters and the inter-relationships.

§ I. SEED AND LINT CHARACTERS

MATERIAL AND SAMPLING

For the complete study of the seed, lint as well as the fibre characters, made in this enquiry, the material consisted of three pure strains, viz. Co 1 (*G. hirustum*), Co 2 (*G. hirsutum*) and Karunganni 546 (*G. indicum*).** For a further detailed study of the seed and lint characters alone, a number of other pure strains were utilized. The sampling was made with the object of eliminating, or reducing to a minimum, almost all the extraneous influences other than the one under enquiry. This was done by confining the picking to that of a single day and that too to as few plants as were necessary and picking only bolls of similar locular composition, either three-locked or four-locked according to the variety of cotton. Even amongst these only such locks that contained no aborted or undeveloped seeds were selected.

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* Part of the thesis submitted for the M.Sc. degree of the Madras University

** These samples are Nos. 1, 2 and 10 of Tables VI—X.

The seeds in the lock were numbered in the following manner, suggested by Rao Bahadur Ramanatha Ayyar. If a lock of cotton is held such that the funicular ends of the seeds face the observer and the tapering end* of the lock points bottomwards (Fig. 1) it will be seen that the seeds are arranged alternately on opposite sides of the medial line. The seeds located on either side belong to two different placenta. If the seed nearest to the pedicel is reckoned as the first, and if this happens to lie on the left side of the medial line, then all the seeds on the left side will bear consecutive odd numbers as we travel downwards, while those on the right side the consecutive even ranks. If the first seed were on the right side, all odd-numbered seeds will occupy that side and even-numbered the other side. It was observed that the occurrence of the first seed either on the right or on the left side of the lock does not follow any definite rule.

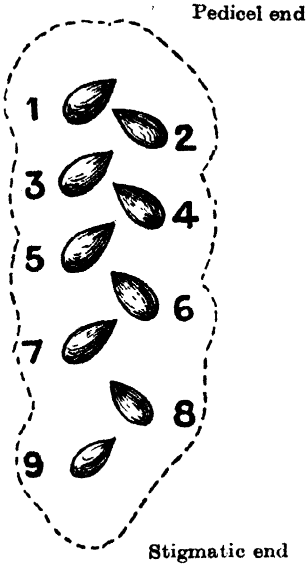

FIG. 1

It may be mentioned here that Sen [1932], who has worked on a similar problem, has taken the seed at the stigmatic end as first and it, therefore, corresponds to the last seed according to the present method of numbering. He has, however, presumed this seed to lie always in the centre and counted the next seed to the left as second. This method of numbering is defective since the first seed should either be on the right or left placentum. In the former case the second seed will be on the left side, while in the latter case it will be on the right side on account of the alternate disposition. The method of taking the seed on the left always as second thus introduces the error of mixing seeds of consecutive positions and masks the inherent difference, if any, between the positions.

EXPERIMENTAL PROCEDURE

The seeds of the corresponding positions of each lock were sorted out and clubbed together. They were carefully delinted by hand so as not to break any of the fibres. The lint and seeds were weighed after drying them in

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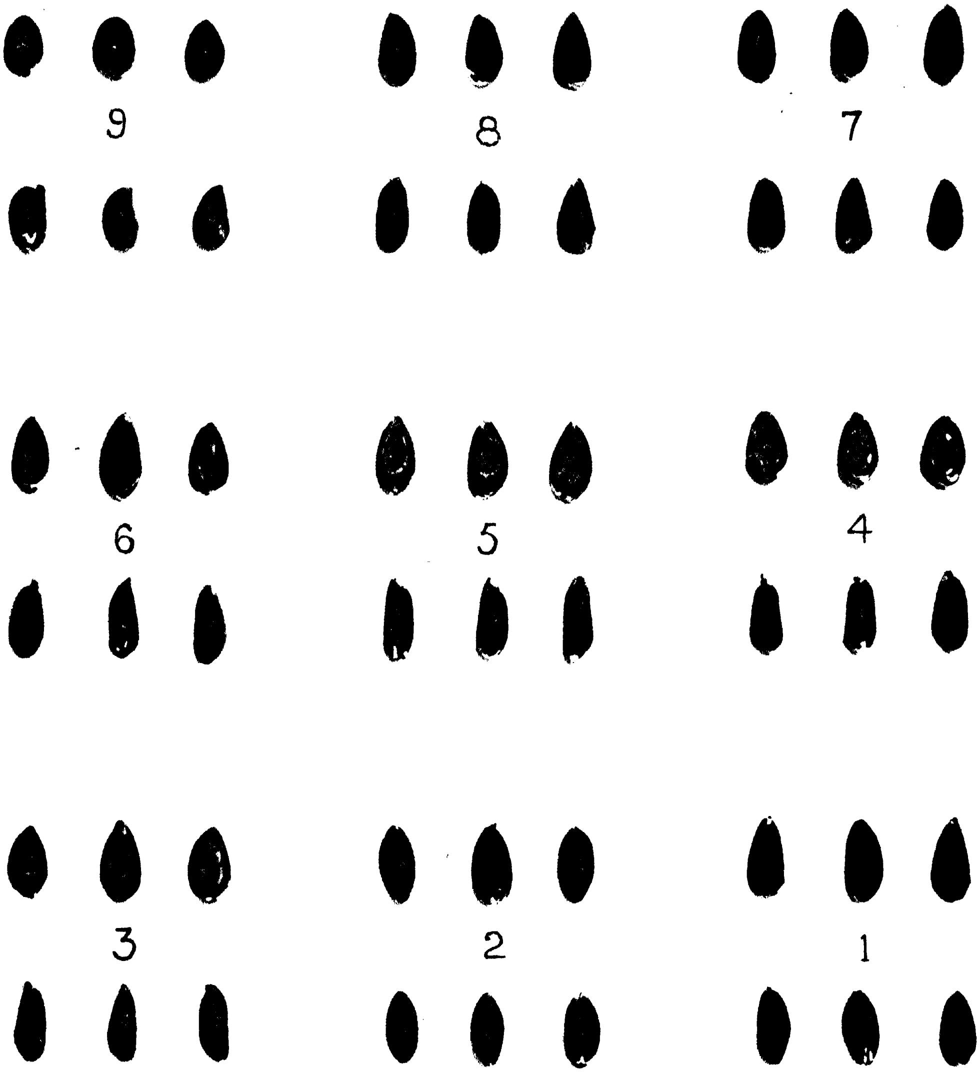
* The tapering end of the lock corresponds to the stigmatic end of the boll.



Co 2

The numbers represent the position of the seed in a lock, 1 corresponding to the pedicel end and 9 to the stigmatic end. Six seeds are shown for each position, the upper three and the lower three indicating the appearance of the seeds in two directions at right angles to each other.

desiccators till the weight became approximately constant. They were used for the study of the following characters.

1. Seed weight
2. Lint weight
3. Ginning percentage
4. Embryo weight
5. Seed-coat weight
6. Fibre length
7. Fibre weight
8. Immaturity of fibres
9. Number of fibres per seed
10. Surface area of the seed

In addition, a further set of 22 samples from pure strains was studied for the verification of the variation in the first five characters. In 12 of them, the total number of seeds in each position was divided into sub-samples of 10 seeds each. Each sub-sample was delinted separately and its seed weight and lint weight were determined. After cutting the seeds open, the embryo weight as well as the seed-coat weight of each sub-sample was also determined. From these individual weights the standard errors were calculated.

The fibre length was determined by making two Balls' Sorter tests on two independent slivers. The fibre weight was obtained by using the cutting method* and determining the weights for the different group-lengths of fibres, following, in all detail, the procedure described in the previous work [Iyengar and Turner, 1930]. For each position five group-lengths were tested and eight weighings of about 250 fibres each were made for each group-length. This method enabled the calculation of the number of fibres per seed**. The maturity of the fibres was estimated by employing Clegg's [1932] method. As in the case of the fibre weight this attribute also was determined for each group-length. But unfortunately, as this investigation was taken up last, sufficient quantity of sliver was not available for all the positions of Co 2 and K 546. Ten tufts containing about 100 fibres in each were examined for Co 1, six tufts for Co 2 and seven for K 546.

In order to estimate the number of fibres per unit area of the seed surface, the surface area of the seeds had to be calculated. Turner [1929] estimated the area as being proportional to $\sqrt[3]{(\text{Seed—volume})^2}$, by assuming that the seeds were, on the average, uniform in shape. Armstrong and Bennett [1933] considered that ' the cotton seed is practically a prolate spheroid ' and calculated the surface area from the external dimensions of the seed using a formula derived under the above assumption. But it will be seen in Plate XXXVII that the seeds dealt with in the present study are not similar in shape. The seeds nearest the stigmatic end are seen to approach the spherical form but for a slight projection near the funicle ; those near the pedicel are three-sided, two sides being concave and the third convex. The seeds in the middle of the lock, though varying among themselves, exhibit the general appearance of a prolate spheroid pressed at the two sides, both the presssed sides being concave.

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* This method was followed since it was in vogue in 1930 and 1931 when this work was carried out.

** As already stated, the lint weight was determined after desiccation, while the fibre weight is that which is corrected to 70 per cent relative humidity. The desiccated samples of lint were kept in a chamber containing a solution of calcium chloride giving a relative humidity of 70 per cent, the increase in weight was determined and the required correction was applied in calculating the number of fibres per seed.

Since concave surfaces, while increasing the area, reduce the volume, the calrelation of the surface area from the external dimensions will not give accurate results in the present case.

The method developed by the writer for the measurement of surface area [Iyengar, 1929] was employed. According to that method the fuzz on the seeds was completely removed by treating the seeds uniformly with concentrated sulphuric acid. The seeds of each position were divided after washing and drying into sub-samples, six lots of 20 seeds for each position in Co 1, four of 20 for Co 2, and four of 32 seeds for K 546. Each of these lots was immersed in liquid paraffin for a definite period and then removed into the tubes of a centrifuge and rotated with a constant head of water for a definite time. With a view to counterbalance the variations, if any, in the speed of rotation of the centrifuge, samples of seeds from different positions were used for the four receptacles. The head of water was kept practically constant throughout the work. As wire-gauze bottoms were provided for the tubes, the excess of liquid drained away and only a thin layer was left on the surface. The increase in the weight of the seeds was taken as a measure of the surface area*.

The seeds of each position were then cut open and the embryos removed carefully from the enclosing coats and their weights were determined.

In addition to these, in strain Co 1 the density of the seeds was determined according to the method described by Turner [1929, 1] by the displacement of liquid paraffin in a specific gravity bottle.

DISCUSSION OF RESULTS

Abraham and Ramanatha Ayyar [1937] have observed that the primor dial ovules are produced alternately on either placenta as we travel from the pedicel towards the stigma and that the ovule nearest the pedicel always aborts, the second one being the first to get fertile. The first seed of the present study is thus the second of the primordial ovules and it is the first seed in one placentum. The second seed is the first fertile seed on the other placentum though it corresponds to the second primordial ovule in that placentum. We may now consider which of the seeds in the two placenta may be taken as being in the same level, whether they are 1 and 2, 3 and 4, etc., or 2 and 3, 4 and 5, etc. The differences** 1—2, 3—4, etc., which we shall for convenience call A, and the differences 2—3, 4—5, etc., which we shall call B, have been calculated. The mean values of A and B for the different species are given in Table I. It will be seen that A is less than B in all cases except for seed weight and embryo weight in *hirsutum* and *cernuum*. But the difference between A and B is not very large nor can its significance be assessed statistically. We may therefore state that, roughly, seeds 1 and 2, 3 and 4, etc. may be more nearly on the same level than 2 and 3, 4 and 5, etc.

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* The centrifuge used for Co 1 was different from that used for Co 2 and K 546. The value of the constant for the last two was, therefore, different from that for the first.

**The arithmetical value of the difference without reference to sign has been considered here, as we are concerned only with the magnitude of the difference and not the direction.

TABLE I

Differences in weights in mg. (between placenta)

Property	Difference	*Hirsutum*		*Herbaceum*		*Arboreum*		*Cernuum*		All cottons	
		A	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Seed weight . .	1—2	3·44		1·92		1·12		2·57		1·88	
	2—3		1·24		1·15		0·88		1·47		1·06
	3—4	1·16		0·06		0·45		1·87		0·79	
	4—5		1·30		2·62		1·85		1·03		1·83
	5—6	2·32		3·60		1·40		0·63		1·86	
	6—7		3·16		5·50		2·84		2·40		3·14
	Mean .	2·31	1·90	1·86	3·09	0·99	1·86	1·69	1·63	1·51	2·01
Embryo weight .	1—2	2·86		1·15		0·88		2·43		1·11	
	2—3		0·96		0·70		0·61		0·93		0·72
	3—4	1·16		0·28		0·46		0·90		0·61	
	4—5		0·78		1·48		1·01		0·53		0·98
	5—6	1·24		1·32		0·98		0·43		1·02	
	6—7		1·66		2·40		1·48		0·57		1·48
	Mean .	1·75	1·13	0·92	1·53	0·77	1·03	1·25	0·68	0·91	1·06
Seed-coat weight .	1—2	1·00		0·62		0·42		1·63		0·71	
	2—3		0·62		0·35		0·71		0·33		0·54
	3—4	0·92		0·42		0·25		0·63		0·46	
	4—5		0·94		1·00		0·71		1·53		0·90
	5—6	0·72		1·12		0·58		0·60		0·70	
	6—7		1·80		2·10		0·78		1·70		1·42
	Mean .	0·88	1·12	0·72	1·15	0·42	0·73	0·95	1·18	0·62	0·95
Lint weight . .	1—2	3·06		1·30		0·65		4·03		1·64	
	2—3		4·52		0·80		1·72		2·80		2·27
	3—4	0·64		0·58		0·85		0·63		0·74	
	4—5		1·56		1·02		1·71		4·27		1·88
	5—6	1·86		1·05		0·77		0·17		0·92	
	6—7		1·98		2·00		1·43		2·10		1·74
	Mean .	**1·85**	**2·69**	**0·98**	**1·27**	**0·76**	**1·62**	**1·68**	**3·06**	**1·10**	**1·96**

TABLE II

Differences in weights in mg. (within a placentum)

Property	Difference	*Hirsutum*		*Herbaceum*		*Arboreum*		*Cernuum*		All cottons	
		C	*D*	*C*	*D*	*C*	*D*	*C*	*D*	*C*	*D*
Seed weight . .	1—3	4·56		3·08		1·35		4·03		2·59	
	2—4		2·00		1·20		0·82		2·67		1·32
	3—5	2·36		3·02		2·15		1·37		2·24	
	4—6		2·30		5·98		3·05		0·73		3·11
	5—7	2·94		8·40		3·72		2·17		3·73	
	Mean .	3·29	2·15	4·87	3·59	2·41	1·94	2·52	1·70	2·85	2·22
Embryo weight .	1—3	3·78		1·85		1·12		3·37		2·04	
	2—4		2·08		0·80		0·77		1·83		1·16
	3—5	1·14		1·38		0·93		1·17		1·07	
	4—6		1·74		2·80		1·75		0·77		1·87
	5—7	1·06		3·50		1·51		0·60		1·77	
	Mean .	1·99	1·41	2·24	1·80	1·19	1·26	1·71	1·30	1·63	1·52
Seed-coat Weight .	1—3	1·14		0·88		0·50		1·37		0·79	
	2—4		1·12		0·32		0·75		0·63		0·74
	3—5	1·86		1·42		0·93		0·97		1·20	
	4—6		1·18		2·12		1·23		1·00		1·34
	5—7	1·98		3·30		1·26		1·17		1·63	
	Mean .	1·66	1·15	1·87	1·22	0·90	0·99	1·17	0·82	1·21	1·04
Lint weight . .	1—3	1·61		1·90		1·54		1·23		1·60	
	2—4		4·40		0·82		2·63		2·17		2·64
	3—5	1·44		1·60		2·51		3·63		2·26	
	4—6		3·42		2·02		2·31		4·30		2·73
	5—7	3·84		2·64		1·88		2·00		2·50	
	Mean .	2·30	3·91	2·05	1·42	1·98	2·47	2·29	3·24	2·12	2·68

We may now consider the variation within the same placentum. The mean differences 1—3, 3—5, etc. which we shall call C and mean differences 2—4, 4—6, which we shall call D, are recorded in Table II. It will be seen that C is greater than D in all cases for seed weight. So also is it for embryo weight and seed-coat weight except in *arboreum*. On the other hand, for lint weight, C is less than D in all cases except in *herbaceum*. It may, therefore, be concluded that, but for a few exceptions, in the placentum in which the first fertile seed appears the difference between successive seeds is greater for seed weight, embryo weight and seed-coat weight and in the other placentum the variation in lint weight is greater.

We may now consider in detail the variation of the characters.

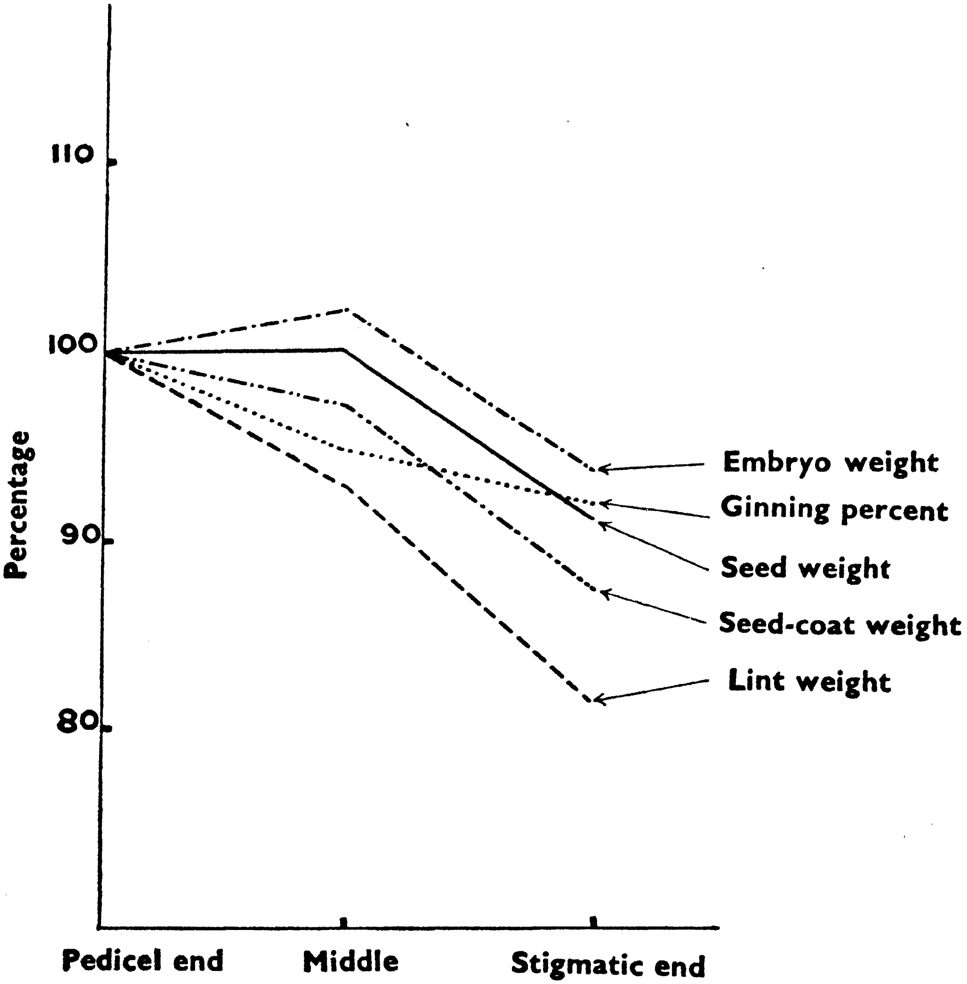

FIG. 2. Variation of characters in different regions

TABLE

Values for the regions expressed as percentage

Property	Pedicel region	Middle region									
		Hirsutum		*Herbaceum*		*Arboreum*		*Cernuum*		All cottons	
		Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.
Seed weight	100	101·24	0·90	102·50	1·11	99·52	0·59	98·07	1·55	100·16	0·48
Embryo weight	100	104·36	0·57	103·88	0·97	101·19	0·87	101·37	2·06	102·28	0·58
Seed-coat weight	100	97·86	0·95	100·15	0·86	97·50	0·72	94·10	0·37	97·59	0·52
Lint weight	100	95·18	1·09	103·70	2·74	89·40	1·50	90·67	0·85	93·00	1·33
Ginning percentage	100	96·04	0·34	100·75	1·51	92·41	1·12	96·13	0·26	94·92	0·86

Seed weight	Pedicel ~ middle	N
	Pedicel ~ stigmatic	N
	Middle ~ stigmatic	N
Embryo weight	Pedicel ~ middle	HS
	Pedicel ~ stigmatic	N
	Middle ~ stigmatic	N
Seed-coat weight	Pedicel ~ middle	N
	Pedicel ~ stigmatic	S
	Middle ~ stigmatic	N
Lint weight	Pedicel ~ middle	HS
	Pedicel ~ stigmatic	HS
	Middle ~ stigmatic	S
Ginning percentage	Pedicel ~ middle	HS
	Pedicel ~ stigmatic	HS
	Middle ~ stigmatic	S

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* Data of mean values for middle and 'stigmatic' regions expressed as percentage

N = Not significant; S = significant for

** Difference very near the value

† Difference very near the value

III

of the value for the pedicel region

Stigmatic region										By analysis of variance* (all cottons)		
Hirsutum		*Herbaceum*		*Arboreum*		*Cernuum*		All cottons		Mean square between regions	Critical difference†	
Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.		P=0 5	P=0·1
97·12	1·50	92·80	1·06	91·67	1·36	80·60	0·83	91·61	1·18	742·08 HS	2·01	2·73
102·32	0·90	94·78	1·30	92·05	2·03	84·60	0·37	93·64	1·46	931·39 HS	2·43	3·30
92·48	1·71	92·78	1·78	90·81	1·34	78·00	1·08	89·85	1·19	748·07 HS	1·82	2·47
87·16	1·64	93·88	3·89	77·86	2·02	71·23	0·89	81·49	1·85	1655·43 HS	1·67	2·28
93·66	0·55	101·12	3·14	88·62	1·98	94·00	0·00	92·27	1·41	87·39 HS	1·36	1·84

N	N	N	N	N
HS	HS	HS	HS	HS
HS	HS	HS	HS	HS
S	NS	N	HS	N**
S	HS	HS	HS	HS
HS	HS	S	HS	HS
N	HS	HS	HS	S†
S	HS	HS	HS	HS
S	HS	HS	HS	HS
N	HS	HS	HS	HS
N	HS	HS	HS	HS
N	HS	HS	HS	HS
N	HS	HS	HS	H
N	HS	HS	HS	HS
N	N	HS	N	HS

of pedicel value—last two columns of Tables VI — X
P = 0·05 ; HS = significant for P = 0·01 ;
for significance for P = 0·05
for significance for P = 0·01

(1) *Seed weight*

The results are given in Table VI. It will be seen that for five samples, viz. K 546(Koilpatti), Verum early, *G. sanguineum* (black soil), Mollisoni and N 14 (black soil), the highest value appears in the second position. For practically all the remaining samples the maximum is reached in a position between the second and the middle of the lock, there being a rise up to that position accompanied by a gradual decline later on. It may be noticed that the rise is rather slow and the fall is more rapid, especially when the number of seeds constituting the lock is large as in *G. cernuum*.

The seeds in the lock may be roughly divided into three regions : (1) pedicel, (2) middle and (3) stigmatic, for it would then be possible to club together cottons with varying locular compositions. The figures are given at the end of Table VI. Taking the value for the pedicel end as 100, the values for the other two regions have been expressed as a percentage of it. The mean values of these percentages when the cottons within a species are clubbed together and when all the cottons are clubbed together are recorded in Table III. The significance of the various differences, according to both standard error and analysis of variance, is also indicated in the same table. It will be seen that for the property under consideration here, namely the seed weight, the three differences in *hirsutum* and the difference between the pedicel and middle regions in the other cases are not significant. The remaining differences are highly significant. This means that the factors responsible for the production of seed weight are equally efficient in the pedicel as well as the middle regions, but far less so in the stigmatic region (excepting in *hirsutum*).

(2) *Embryo weight*

The values for this character are reproduced in Table VII. For N 14 (black soil) the highest value is in the first and second positions. Three samples, namely K 546 (Koilpatti), *G. sanguineum* (black soil) and Mollisoni, record the highest value in the second position and all the rest of the samples in approximately the middle of the lock. The rise and fall appears to be similar to that observed in the case of the seed weight though not of such a magnitude.

The percentage values for the three regions denote that all the differences excepting four are significant. (It will be seen that the difference between the pedicel and middle regions is significant according to the standard error, while according to the analysis of variance it is not. The difference is, however, near the value required for significance in the latter case). This means that, excepting in *arboreum* and *cernuum*, the embryo weight is highest in the middle region, less in the pedicel region and still less in the stigmatic region (excepting in *hirsutum*). The activity for the production of the embryo weight thus appears to be maximum in the middle of the lock (Fig. 2).

(3) *Seed-coat weight*

The figures are found in Table VIII. It will be seen that about half the number of cottons have the maximum value in the second position and the remaining in a position intermediate between the second and the centre of the lock. There is a gentle rise up to the maximum with a fall later.

The percentages in the different regions denote that all the differences except three are significant. The pedicel region records the highest value, the middle a lower one and the stigmatic region a much lower value. The activity that produces this character may, therefore, be said to deteriorate gradually with the distance from the pedicel.

(4) *Lint weight*

These results are given in Table IX. For three cottons, namely K 546 (Coimbatore, five seeded) and both samples of N 14, the highest weight is in the first position. For four others, namely Nadam, 2405 (black soil) and both samples of 2919, it is approximately in the middle of the lock. For almost all the remaining samples the maximum value is found in the second position, there being a rise from the first to the second position followed by a gradual decrease towards the end of the lock. The fall in lint weight is much greater than in the other characters for most of the cottons.

When the percentage values for the regions are considered, it will be seen that, excepting the three differences for *herbaceum*, all are highly significant. The activity for the production of lint is thus greatest near the pedicel, less in the middle and least near the end of the lock, gradually decreasing with the distance from the source of food supply (excepting in *herbaceum*).

(5) *Ginning percentage*

Table X contains the results. Four samples, namely Nadam, Mollison and both samples of 2919 denote little fluctuation among the positions. 2405 (black soil) records a gradual increase with advance of position. Three samples of K 546 (Coimbatore) and two of N 14 exhibit the maximum value in the first position. Most of the remaining samples record the highest value in the second position, there being a continuous fall towards the end of the lock.

The values for the regions exhibit a behaviour almost similar to that shown by the lint weight, the percentage decreasing significantly with the distance from the pedicel excepting in the *herbaceum* cotton.

Summing up the foregoing conclusions, it may be stated that the lint is produced in the largest quantity nearest the source of food supply and decreases rapidly with the distance from the source. The embryo, on the other hand, is produced in the largest quantity rather farther from the source of food supply, that is near the middle of the lock. The seed-coat which comes in between the embryo and lint exhibits an intermediate trend of variation. The seed which is composite of the embryo and seed-coat follows a middle course (Fig. 2). In *G. cernuum* the number of seeds in a lock is considerably more than that in other cottons, being nearly double. Hence the nutrition will have to travel a longer length to reach the distal end (stigmatic region) of the lock. The reduction in the seed weight, lint weight, embryo weight and seed-coat weight at the stigmatic end for this cotton is found to vary from 15 to 30 per cent, which is considerably more than what is observed in cottons with fewer seeds in the lock.

The foregoing conclusions, namely the largest deposition of cellulose (lint) being nearest the source of food supply, while that of proteins, fats, minerals, etc. (embryo) being farther from it appears to be rather a paradox. Some cytological or physiological investigation may throw light on this.

Incidentally, we may record the effects, observed in the present investigation, of variation in the number of seeds in the lock and of the kind of soil in which the plants were grown. The figures are found in Tables VI—X. It will be seen generally that the mean values of the seed weight and embryo weight exhibit an increase with the decrease in the number of seeds constituting a lock, though this is not always strictly true. The ginning percentage and seed-coat weight remain practically unaffected. Coming to the soil variation, it will be seen that the red soil* has produced greater seed weight, embryo weight and seed-coat weight in all the three strains studied, viz. N 14, 2405 and *G. sanguineum*. More lint weight is also produced by the same soil except in N 14. This strain records a reduction in the red soil for ginning percentage. In the other two strains the difference is not large.

(6) *Surface area of seed*

The results are given in Table IV.

TABLE IV

Surface area of seeds in arbitrary units

Position of seeds	Co 1 (×*k*)	Co 2 (×*k*¹)	K 546 (×*k*¹)
Pedicel end —			
I	1.71	1.72	0.80
II	1.82	1.85	0.84
III	1.83	1.82	0.83
IV	1.76	1.87	0.80
V	1.80	1.86	0.80
VI	1.81	1.86	0.80
VII	1.81	1.81	0.81
VIII	1.80	1.83	..
IX	1.83	1.76	..
Stigmatic end—			

Except for a rise from the first to the second position there does not appear to be much fluctuation in the surface area.

(7) *Density of seed*

The results which were obtained from Co 1 only are given in Table V.

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*Irrigation was given in the red soil but not in black soil.

TABLE V

Density of seeds

Position of seed	Density in gm. per c.c.
Pedicel end—	
I	1.006
II	1.003
III	1.020
IV	1.013
V	1.011
VI	0.999
VII	0.978
VIII	0.978
IX	0.976
Stigmatic end—	

The density appears roughly to rise up to about the middle of the lock with a fall later.

CONCLUSION

(1) The lint is found to be produced in the largest quantity alomst nearest the source of food supply and decreases rapidly towards the end of the lock except in *herbaceum.*

(2) The embryo has the highest weight rather farther from the source of food supply than was found in the case of the lint. The decrease towards the end of the lock is also less marked.

(3) The seed-coat, which comes in between the embryo and the lint, exhibits an intermediate trend of variation.

(4) The seed, which is a composite of the embryo and seed-coat, follows a middle course.

(5) The foregoing conclusion, viz. the highest deposition of cellulose (lint) being nearest the source of food supply, while that of proteins, fats, minerals, etc. (embryo) being rather farther from it appears to be a paradox. Further cytological or physiological work may throw some light on this paradox.

(6) The ginning percentage is highest in the pedicel region and decreases with advance of position except in *G. herbaceum.*

(7) The seed weight, lint weight and embryo weight are generally (though not universally) found to increase with the reduction in the number of seeds constituting the lock.

(8) The red soil (which was irrigated) is found to produce an increase in seed weight, embryo weight and seed-coat weight in all the three strains studied and an increase in lint weight also in two of them, over the black soil (which was not irrigated). The same red soil has caused a reduction in the ginning percentage in one strain but not much difference in the other two.

(9) Except for a rise from the first to the second position there does not appear to be much variation in the surface area of the seeds.

(10) Roughly speaking the density of the seed may be said to rise up to the middle of the lock with a fall later.

TABLE

Seed

No.*	Name of cotton	No. of seeds in lock	Species	Soil	Pedicel end					Posi-
					1	2	3	4	5	6
1	Co 1	9	*G. hirsutum*	Red	116·1	118·9	122·1	122·6	124·5	126·2
					119·0			124·4		
2	Co 2	9	Do.	,,	136·8	139·7	140·0	141·0	138·2	141·7
					138·8			140·3		
3	Co 1	9	Do.	,,	118·0	121·1	122·3	121·9	120·1	120·7
					120·5			120·9		
4	Do.	8	Do.	,,	123·1	128·1	129·3	128·7	128·1	125·6
					126·8			128·4		
5	Do.	7	Do.	,,	125·0	128·4	128·1	124·8	123·9	121·6
					126·7		125·6			121
6	2405	6	*G. herbaceum*	Black	52·5	54·3	55·9	54·9	50·4	47·2
					53·4		55·4		48·8	
7	2405	7	Do.	Red	60·9	62·3	62·3	61·3	60·6	56·8
					61·6		61·4			54
8	2919	6	Do.	Black	69·1	70·9	71·2	71·	68·6	64·2
					70·0		71·4		66·4	
9	2919	7	Do.	,,	67·5	70·2	72·9	72·8	70·4	68·4
					68·8		72·0			64
10	K 546 (Koilpatti)	7	*G. indicum*	Black	53·9	55·4	54·2	53·9	52·7	52·3
					54·6		53·6			51
11	K 546 (Coimbatore)	8	Do.	,,	50·7	52·3	53·0	52·6	50·7	51·9
					52·0			51·6		
12	Do.	7	Do.	,,	50·6	52·1	52·1	52·0	51·5	50·2
					51·4		51·9			49
13	Do.	6	Do.	,,	54·1	55·3	55·8	55·2	53·3	51·3
					54·7		55·5		52·3	
14	Do.	5	Do.	,,	57·1	58·2	57·6	57·6	55·7	
					57·6		57·6	56·6		
15	N 14	6	Do.	,,	40·7	41·3	40·5	39·6	36·3	34·5
					41·0		40·0		35·4	
16	Do.	6	Do.	Red	49·3	49·3	50·7	48·8	48·3	45·0
					49·3		49·8		46·6	
17	Verum early	9	*G. neglectum*	Red	51·4	51·8	50·9	50·8	48·7	48·7
					51·4			49·6		
18	Chandajari	7	Do.	,,	49·5	50·8	51·9	51·9	49·7	49·1
					50·1		51·2			47
19	Mollisoni	8	Do.	,,	59·8	59·6	58·0	58·7	56·7	55·9
					59·1			57·7		
20	Nadam	7	*G. obtusifoleum*	Red	49·8	51·6	52·4	52·5	50·5	48·5
					50·7		51·8			46
21	*G. sanguineum*	7	*G. sanguineum*	Black	38·5	40·8	39·4	38·8	35·8	34·2
					39·6		38·3			32
22	Do.	7	Do.	Red	44·8	45·8	46·2	46·4	44·8	43·0
					45·3		45·8			41
23	*G. cernuum*	16	*G. cernuum*	Red	73·0	77·4	80·0	79·0	79·9	80·4
					77·8					
24	Do.	15	Do.	,,	80·6	82·9	83·4	84·3	85·1	84·5
					83·7					
25	Do.	14	Do.	,,	77·3	78·3	79·6	83·3	81·9	82·7
					80·1					

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* Nos. 1, 2 and 10 constituted

VI

weight

tion					Stigmatic end					Mean	Regional mean as percentage of pedicel value		
7	8	9	10	11	12	13	14	15	16		Pedicel	Middle	Stigmatic
123·0	120·9 121·5	120·5								121·6	100·0	104·5	102·2
138·0	134·0 135·8	135·5								138·3	100·0	101·1	97·8
116·3	110·6 112·0	110·9								118·0	100·0	100·2	93·0
121·6 122·5	120·2									125·6	100·0	101·3	96·6
121·1 ·4										124·7	100·0	99·1	96·0
•										52·5	100·0	103·8	91·5
52·9 ·8										59·6	100·0	99·6	90·5
										69·2	100·0	102·0	95·0
61·3 ·8										69·1	100·0	104·6	94·2
50·2 ·2										53·2	100·0	98·1	93·6
49·6 50·1	48·8									51·5	100·0	99·1	96·3
47·9 ·0										50·9	100·0	101·0	93·5
										54·2	100·0	101·5	95·5
										57·2	100·0	100·0	98·1
										38·8	100·0	97·5	86·4
										48·6	100·0	101·0	93·5
47·3	43·7 44·1	41·2								48·3	100·0	96·5	85·7
45·2 ·2										49·7	100·0	102·1	94·0
53·2 52·8	49·4									56·4	100·0	97·5	89·3
44·0 ·2										49·9	100·0	102·2	91·0
30·1 ·2										36·8	100·0	96·2	80·9
40·7 ·8										44·5	100·0	101·0	92·1
79·7	80·3 77·8	76·6	76·1	74·0	69·0	65·6	62·2 62·3	57·8	56·9	73·0	100·0	100·0	80·2
80·7	81·2 79·5	78·0	73·1	72·9	71·4	67·9 66·4	61·7	58·0		76·4	100·0	95·0	79·4
80·0 79·5	79·5	75·9	72·5	69·2	66·9 65·8	59·1	61·1			74·8	100·0	99·2	82·2

the samples for the main study.

TABLE

Embryo

No.*	Name of cotton	No. of seeds in lock	Botanical species	Soil	Pedicel end					Posi-
					1	2	3	4	5	6
1	Co 1 . .	9	*G. hirsutum* .	Red	63·9	67·2	68·0	69·2	70·4	71·5
					66·4			70·4		
2	Co 2 . . .	9	Do. .	,,	75·6	78·5	79·5	80·5	80·8	83·0
					77·9			81·4		
3	Co 1 . . .	9	Do. .	,,	67·6	69·6	71·8	72·5	72·0	73·8
					69·5			72·8		
4	Do. . . .	8	Do. .	,,	69·5	73·0	73·3	75·0	74·8	76·1
					71·9			74·9		
5	Do. . . .	7	Do. .	,,	71·5	74·1	74·4	75·6	74·1	74·1
					72·8		74·7			73
6	2405 . . .	6	*G. herbaceum* .	Black	25·6	26·4	27·8	27·6	25·0	23·2*
					26·0		27·7		24·1	
7	2405 . . .	7	Do. .	Red	31·4	32·3	32·5	32·6	32·1	30·5
					31·8		32·4			29
8	2919 . . .	6	Do. .	Black	34·1	35·7	35·9	36·2	34·6	33·3
					34·9		36·0		34·0	
9	2919 . . .	7	Do. .	,,	33·4	34·7	35·7	35·9	34·7	34·1
					34·0		35·4			32
10	K 546 Koilpatti .	7	*G. indicum* . .	Black	30·7	32·9	32·3	32·5	31·7	30·8
					31·8		32·2			30
11	K 546 Coimbatore	8	Do. .	,,	25·5	26·6	27·4	28·2	27·4	27·0
					26·5			27·8		
12	Do. .	7	Do. .	,,	26·6	28·4	28·2	28·5	28·1	27·1
					27·5		28·3			26
13	Do. .	6	Do. .	,,	29·3	29·7	30·7	30·3	30·2	28·1
					29·5		30·5		30·1	
14	Do. .	5	Do. .	,,	30·9	31·5	31·3	31·0	29·5	
					31·2		31·3	30·2		
15	N 14 . . .	6	Do. .	,,	21·6	21·6	21·2	20·6	18·4	17·0
					21·6		20·9		17·7	
16	Do. . . .	6	Do. .	Red	26·7	27·4	28·2	27·2	27·4	25·6
					27·0		27·7		26·5	
17	Verum early .	9	*G. neglectum* .	Red	27·9	28·0	27·4	28·3	27·5	27·6
					27·8			27·8		
18	Chandajari .	7	Do. .	,,	27·1	28·2	28·6	29·1	27·9	27·4
					27·6		28·5			26
19	Mollisoni . .	8	Do. .	,,	34·2	35·0	33·9	33·8	32·7	32·4
					34·4			33·2		
20	Nadam . .	7	*G. obtusifolium* .	Red	25·4	26·7	27·5	27·6	26·4	25·7
					26·0		27·2			24
21	*G. sanguineum* .	7	*G. sanguineum* .	Black	20·9	21·6	21·1	20·9	19·0	17·6
					21·2		20·3			16
22	Do. .	7	Do. .	Red	25·2	25·8	26·3	26·9	26·0	24·9
					25·5		26·4			24
23	*G. cernuum* .	16	*G. cernuum* .	Red	30·0	32·8	34·5	35·2	35·4	36·2
					33·4					
24	Do. .	15	Do. .	,,	33·2	35·3	36·4	36·8	37·8	38·0
					35·9					
25	Do. .	14	Do. .	,,	34·1	36·5	36·5	38·1	37·7	38·2
					36·5					

* Nos. 1, 2 and 10 constituted the

VII

weight

tion			Stigmatic end							Mean	Regional mean as percentage of pedicel value		
7	8	9	10	11	12	13	14	15	16		Pedicel	Middle	Stigmatic
70·2	70·0	68·6								68·8	100	106·0	104·5
	69·4												
82·5	81·7	79·3								79·9	100	104·5	104·3
	81·2												
72·0	69·1	68·2								70·7	100	104·6	100·3
	69·8												
73·1	70·6									73·2	100	104·2	102·0
73·3													
72·4										73·7	100	102·5	100·5
·2													
										26·9	100	106·5	92·7
28·3										31·4	100	101·9	92·4
·4													
										35·0	100	103·1	97·5
31·5										34·3	100	104·0	96·5
·8													
30·5										31·6	100	101·2	84·3
·6													
25·7	25·2									26·6	100	105·0	98·0
26·0													
25·8										27·5	100	102·9	96·0
·4													
										29·7	100	103·2	102·0
										30·8	100	100·3	96·8
										20·1	100	96·7	82·0
										27·1	100	102·6	98·2
26·3	24·9	22·8								26·7	100	100·0	89·0
	24·7												
25·6										27·7	100	103·2	94·2
·5													
31·7	29·4									32·9	100	96·5	90·7
31·2													
22·9										26·0	100	104·7	93·5
·3													
14·9										19·4	100	95·7	76·4
·2													
23·8										25·6	100	103·5	95·6
·4													
35·9	36·4	35·1	34·5	33·4	31·9	30·0	28·6	26·1	25·0	32·6	100	105·3	84·3
		35·2					28·3						
36·8	37·8	34·4	33·8	32·9	32·6	30·4	27·4	27·0		34·0	100	100·5	84·1
	36·1					30·2							
38·0	37·8	35·6	35·2	32·7	31·9	27·8	27·8			34·8	100	98·3	85·3
	35·9				31·1								

samples for the main study.

TABLE

Seed-coat

No.	Name of cotton	No. of seeds in lock	Botanical species	Soil	Pedicel end					Posi-
					1	2	3	4	5	6
1	Co 1 . . .	9	*G. hirsutum* .	Red	39·7	40·9	41·3	41·3	41·2	41·0
					40·6			41·2		
2	Co 2 . . .	9	Do. .	,,	42·5	43·8	43·3	43·2	41·3	41·7
					43·2			42·1		
3	Co 1 . . .	9	Do. .	,,	53·5	54·2	55·2	54·0	52·8	52·4
					54·3			53·1		
4	Do. . . .	8	Do. .	,,	54·0	55·1	55·1	53·6	52·9	51·3
					54·7			53·2		
5	Do. . . .	7	Do. .	,,	54·1	54·8	53·7	51·9	51·1	52·1
					54·4		52·2			50
6	2405 . . .	6	*G. herbaceum* .	Black	28·2	28·0	28·3	27·9	26·8	25·9*
					28·1		28·1		26·4	
7	2405 . . .	7	Do. .	Red	29·9	30·4	30·4	29·9	28·9	27·3
					30·2		29·7			26
8	2919 . . .	6	Do. .	Black	35·7	36·6	36·8	36·4	35·5	34·3
					36·2		36·6		34·9	
9	2919 . . .	7	Do. .	,,	35·7	36·6	37·5	37·1	36·1	35·3
					36·2		36·9			34
10	K 546 (Koilpatti)	7	*G. indicum* . .	Black	21·2	22·1	21·6	21·4	20·6	20·4
					21·6		21·2			20
11	K 546 (Coimbatore)	8	Do. . .	,,	23·6	23·7	23·7	23·8	23·5	23·0
					23·7			23·6		
12	Do. .	7	Do. . .	,,	23·5	24·7	23·7	23·5	23·3	22·5
					24·1		23·5			22
13	Do. .	6	Do. . .	,,	26·0	26·0	26·2	25·9	25·2	24·2
					26·0		26·0		24·7	
14	Do. .	5	Do. . .	,,	26·7	26·3	25·6	25·6	24·4	
					26·5		25·6	25·0		
15	N 14 . . .	6	Do. . .	,,	19·4	19·8	19·5	19·3	18·7	18·3
					19·6		19·4		18·5	
16	Do. . . .	6	Do. . .	Red	22·2	22·4	22·5	21·5	21·5	20·4
					22·3		22·0		21·0	
17	Verum early .	9	*G. neglectum* .	Red	23·8	24·1	22·6	22·5	21·7	21·8
					23·5			22·0		
18	Chandajari .	7	Do. .	,,	23·3	23·7	24·0	23·7	22·9	22·2
					23·5		23·5			21
19	Mollisoni . .	8	Do. .	,,	26·3	26·4	25·0	24·8	23·7	23·3
					25·9			24·2		
20	Nadam . .	7	*G. obtusifoleum* .	Red	24·7	25·3	24·9	25·0	24·4	23·7
					25·0		24·8			22
21	*G. sanguineum* .	7	*G. sanguineum* .	Black	18·9	19·3	18·5	18·1	16·9	16·6
					19·1		17·8			16
22	Do. .	7	Do. .	Red	20·1	20·5	19·8	19·6	18·7	17·9
					20·3		19·4			17
23	*G. cernuum* .	16	*G. cernuum* .	Red	41·8	44·0	44·1	44·9	42·7	44·0
					43·5					
24	Do.	15	Do. .	,,	44·8	46·6	46·2	46·1	45·0	44·9
					45·7					
25	Do. .	14	Do. .	,,	43·1	44·0	43·5	44·5	43·2	43·6
					43·7					

* For samples 1, 2 and 10 the seed-coat weight was determined after

VIII

weight

tion				Stigmatic end						Mean	Regional mean as percentage of pedicel value		
7	8	9	10	11	12	13	14	15	16		Pedicel	Middle	Stigmatic
40·6	40·0	39·8								40·6*	100	101·3	98·7
	40·1												
39·3	37·6	38·2								41·2*	100	97·5	89·0
	38·4												
50·3	48·5	47·7								52·0	100	97·7	90·0
	48·8												
49·9	48·8									52·6	100	97·0	91·4
50·0													
49·4										52·4	100	95·8	93·3
·8													
										27·5	100	99·6	94·0
25·3										28·9	100	98·0	87·0
·3													
										35·9	100	101·1	96·4
33·1										35·9	100	101·9	91·7
·2													
20·3										21·1*	100	98·2	94·5
·4													
22·7	21·8									23·2	100	99·6	84·4
22·5													
21·9										23·3	100	97·0	91·8
·2													
										25·6	100	100·0	95·0
										25·7	100	99·6	99·4
										19·2	100	90·0	94·5
										21·8	100	98·6	94·1
20·8	19·9	18·9								21·8	100	93·6	84·7
	19·9												
21·5										23·0	100	100·0	92·8
·8													
22·3	21·4									24·2	100	93·5	86·0
22·3													
21·9										24·3	100	99·2	91·1
·8													
15·9										17·7	100	93·2	84·9
·2													
17·1										19·1	100	96·0	87·6
·5													
42·5	42·4	40·4	39·8	38·5	36·9	34·7	33·9	32·0	31·3	39·6	100	94·4	77·7
	41·1						33·8						
43·2	43·2	41·2	40·1	38·3	36·6	35·0	32·4	32·2		41·1	100	93·0	76·3
	42·5					34·9							
41·7	41·4	39·1	38·7	36·1	34·7	32·5	32·4			39·9	100	94·9	80·0
	41·4				34·9								

removing the fuz by treating the seeds with sulphuric acid.

TABLE

Lint

No.	Name of cotton	No. of seed in lock	Botanical species	Soil	Pedicel end					Posi-
					1	2	3	4	5	6
1	Co 1 . . .	9	*G. hirsutum* .	Red	69·3	73·0 70·7	69·9	68·6	68·4 68·4	68·2
2	Co 2 . . .	9	Do. .	,,	80.6	82·2 80·1	77·5	77·7	75·8 74·4	75·6
3	Co 1 . . .	9	Do. .	,,	67·1	70·1 68·0	66·8	66·8	64·4 64·8	63·1
4	Do. . . .	8	Do. .	,,	75·0	77·4 75·2	73·1	73·4 73·2	72.9	69.4
5	Do. . . .	7	Do. .	,,	74·9 77·2	79·5	72·3	73·7 72·3	70·9	66·8 65
6	2405 . . .	6	*G. herbaceum* .	Black	15·5 16·0	16·4	17·8 17·7	17·6	17·0 16·6	16·2*
7	2405 . . .	7	Do. .	Red	20·7 21·4	22·2	21·8	21·3 21·0	19·8	18·8 18
8	2919 . . .	6	Do. .	Black	25·1 25·8	26·6	27·0 26·4	25·9	25·4 24·4	23·5
9	2919 . . .	7	Do. .	,,	25·1 25·8	26·4	27·4	26·9 26·6	25·4	25·1 23
10	K 546 (Koilpatti)	7	*G. indicum* . .	Black	25·6 25·8	26·0	23·1	22·2 21·5	19·2	18·2 17
11	K 546 (Coimbatore)	8	Do. . .	,,	24·9	26·1 25·4	25·1	24·4 23·1	21·8	21·1
12	Do. .	7	Do. . .	,,	26·8 27·0	27·2	25·2	24·2 23·7	21·8	20·9 20
13	Do. .	6	Do. . .	,,	28·9 29·0	29·2	26·3 25·0	23·7	22·4 21·4	20·3
14	Do. .	5	Do. . .	,,	30·8 30·4	29·9	26·4 26·4	25·2 23·6	22·1	
15	N 14 . . .	6	Do. . .	,,	14·7 14·6	14·6	13·4 13·4	13·3	12·0 11·6	11·1
16	Do. . . .	6	Do. . .	Red	14·8 14·6	14·3	13·7 13·2	12·7	12·3 11·6	10·9
17	Verum early .	9	*G. neglectum* .	Red	25·0	25·8 24·5	22·7	22·5	20·8 20·7	19·4
18	Chandajari .	7	Do. .	,,	14·7 15·1	15·6	14·5	13·5 13·6	12·7	12·5 11
19	Mollisoni . .	8	Do. .	,,	32·4	32·9 32·1	31·0	30·5 29·8	29·0	29·3
20	Nadam . .	7	*G. obtusifolium* .	Red	13·3 13·7	14·1	14·3	14·6 14·2	13·7	13·4 13
21	*G. sanguineum* .	7	*G. sanguineum* .	Black	20·0 20·6	21·1	19·2	18·5 18·2	17·0	16·9 16
22	Do. .	7	Do. .	Red	23·5 23·8	24·0	22·1	21·3 21·2	20·1	19·7 19
23	*G. cernuum* .	16	*G. cernuum* .	Red	75·4	79·1	77·6 77·1	78·9	74·3	74·2
24	Do .	15	Do. .	,,	82·8	87·4	83·8 83·5	84·0	79·5	79·9
25	Do. .	14	Do. .	,,	80·1	83·9	80·6 80·6	81·0	77·3	77·3

---

* Nos. 1, 2, and 10 constituted

IX

weight

ion			Stigmatic end							Mean	Regional mean as percentage of pedicel value		
7	8	9	10	11	12	13	14	15	16		Pedicel	Middle	Stigmatic
67·9	65·6 66·1	64·7								68·4	100	96·8	93·5
73·7	66·4 68·4	65·2								75·0	100	92·8	85·4
61·9	57·3 58·2	55·3								63·6	100	95·3	85·5
66·3 65·4	60·6									71·0	100	97·4	87·0
63·4 ·1										71·6	100	93·6	84·4
										16·6	100	111·3	103·8
17·5 ·2										20·3	100	98·2	85·0
										25·6	100	102·3	94·5
22·4 ·8										25·5	100	103·0	92·2
17·1 ·6										21·6	100	83·4	68·2
19·6 19·9	19·0									22·7	100	91·0	78·4
19·3 ·1										23·6	100	87·7	74·5
										25·1	100	86·3	73·8
										26·9	100	86·8	77·6
										13·2	100	91·7	79·4
										13·1	100	90·3	79·4
18·3	16·7 16·6	14·9								20·6	100	81·1	65·0
11·0 ·8										13·5	100	90·0	78·2
27·4 27·4	25·6									29·8	100	92·8	85·3
12·5 ·0										13·7	100	103·7	95·0
15·2 ·C										18·3	100	88·4	77·7
18·8 ·0										21·3	100	89·0	79·7
74·0	73·0	70·1 70·8	68·3	65·2	62·3	59·1	55·4 54·2	48·6	45·6	67·6	100	91·8	70·2
76·3	73·9 74·3	72·3	69·1	65·6	63·4	59·8 58·9	55·2	50·4		72·2	100	89·0	70·5
74·8	77·2 73·6	65·1	66·1	63·0	60·1 58·8	54·4	50·4			70·8	100	91·2	73·0

the samples for the main study.

TABLE

Ginning

No.	Name of cotton	No. of seed in lock	Botanical species	Soil	Pedicel end				Post	
					1	2	3	4	5	6
1	Co 1	9	*G. hirsutum*	Red	37·4	38·1	36·4	35·7	35·5	35·1
						37·5			35·4	
2	Co 2	9	Do.	,,	37·1	37·1	35·7	35·5	35·4	34·8
						36·6			35·2	
3	Co 1	9	Do.	,,	36·2	36·6	35·3	35·4	34·9	34·4
						36·0			34·9	
4	Do.	8	Do.	,,	37·8	37·6	36·0	36·3	36·2	35·6
						37·1		36·2		
5	Do.	7	Do.	,,	37·4	38·2	36·0	37·1	36·4	35·4
					37·8			36·5		34
6	2405	6	*G. herbaceum*	Black	22·8	23·2	24·1	24·2	25·8	25·6
					23·0		24·2		25·4	
7	2405	7	Do.	Red	25·4	26·3	25·9	25·8	24·7	24·8
					25·8			25·5		24
8	2919	6	Do.	Black	26·6	27·3	27·5	26·6	27·0	26·8
					27·0		27·0		26·9	
9	2919	7	Do.	,,	27·1	27·4	27·3	27·0	26·5	26·8
					27·2			26·9		26
10	K 546 (Koilpatti)	7	*G. indicum*	Black	32·2	32·0	29·9	29·2	26·7	25·8
					32·1			28·6		25
11	K 546 (Coimbatore)	8	Do.	,,	32·9	33·5	32·1	31·7	29·2	28·9
						32·8		30·4		
12	Do.	7	Do.	,,	34·6	34·3	32·7	31·7	29·7	29·4
					34·4			31·4		29
13	Do.	6	Do.	,,	37·4	34·5	32·0	30·0	29·6	28·4
					36·0		31·0		29·0	
14	Do.	5	Do.	,,	35·0	33·9	31·4	30·4	28·4	
					34·4		31·4	29·4		
15	N 14	6	Do.	,,	26·5	26·1	24·9	25·1	24·9	24·2
					26·3		25·0		24·6	
16	Do.	6	Do.	Red	23·0	22·5	21·5	20·7	20·3	19·4
					22·8		21·1		19·8	
17	Verum early	9	*G. neglectum*	Red	32·7	33·2	30·8	30·7	29·5	28·5
						32·2			29·6	
18	Chandajari	7	Do.	,,	22·8	23·5	21·8	20·7	20·3	20·2
					23·2			20·9		19
19	Mollisoni	8	Do.	,,	35·1	35·6	34·8	34·2	33·9	34·4
						35·2		34·0		
20	Nadam	7	*G. obtusifolium*	Red	21·1	21·5	21·5	21·8	21·3	21·7
					21·3			21·5		22
21	*G. sanguineum*	7	*G. sanguineum*	Black	34·2	34·1	32·8	32·4	32·2	33·1
					34·2			32·5		33
22	Do.	7	Do.	Red	34·4	34·5	32·4	31·4	30·9	31·4
					34·4			31·6		31
23	*G. cernuum*	16	*G. cernuum*	Red	50·7	50·5	49·2	49·8	48·2	48·3
							49·5			
24	Do.	15	Do.	,,	50·6	51·3	50·0	49·8	48·3	48·6
							50·0			
25	Do.	14	Do.	,,	50·8	51·7	50·2	49·2	48·5	48·3
							50·1			

* Nos. 1, 2 and 10

X

percentage

tion		Stigmatic end								Mean	Regional mean as percentage of pedicel value		
7	8	9	10	11	12	13	14	15	16		Pedicel	Middle	Stigmatic
35·6	35·2	34·9								36·0	100	94·9	94·3
	35·2												
34·9	33·1	32·5								35·1	100	96·2	91·5
	33·5												
34·7	34·2	33·2								35·0	100	96·8	94·5
	34·0												
35·3	33·5									36·1	100	96·6	94·0
–34·8													
34·4										36·5	100	95·7	94·0
·9													
*										24·2	100	105·2	110·3
24·8										25·2	100	98·8	96·1
·8													
										27·0	100	100·0	99·6
26·8										27·0	100	99·0	98·5
·8													
25·4										28·7	100	86·0	79·7
·6													
28·3	28·0									30·6	100	92·6	86·5
–28·4													
28·7										31·6	100	91·2	81·3
·0													
										31·6	100	86·1	80·6
										31·8	100	91·3	85·5
										25·3	100	95·0	93·5
										21·2	100	92·5	86·8
27·8	27·6	26·6								29·7	100	92·0	84·8
	27·3												
19·6										21·3	100	90·0	85·8
·9													
34·0	34·1									34·5	100	96·6	97·0
–34·2													
22·2										21·6	100	101·0	103·2
·0													
33·6										33·2	100	95·0	96·6
·4													
31·0										32·3	100	92·0	90·7
·2													
48·1	47·6	47·8	47·2	46·7	47·4	47·4	47·3	45·6	44·7	48·4	100	96·1	94·0
	47·6						46·5						
48·6	47·7	48·0	48·5	47·3	47·0	46·9	47·2	46·5		48·5	100	96·6	94·0
	48·3					47·0							
48·3	49·2	46·2	47·7	46·6	47·3	48·0	45·2			48·7	100	95·7	94·0
	48·0				47·2								

constituted the samples for the main study

§II. FIBRE CHARACTERS

In § I the seed and lint characters were considered. The fibre characters will be dealt with in the following :—

(*a*) *Fibre length*

The results are recorded in Table XI.

TABLE XI

Mean fibre length in inches

Position of seed	Co 1	Co 2	K 546
Pedicel end—			
I	1·02	1·00	0·96
II	1·02	1·00	0·98
III	1·04	1·03	1·03
IV	1·02	1·02	1·02
V	1·03	1·02	1·01
VI	1·04	1·04	0·99
VII	1·04	1·06	0·95
VIII	1·04	1·05	..
IX	1·02	1·06	..
Stigmatic end—			

In Co 1 there does not appear to be much fluctuation. In Co 2 the first seed has the shortest length and the last seed the longest, the increase appearing to be gradual in the intermediate positions. In K 546 also the differences are large though the trend of variation is different. There is an increase in length up to the middle of the lock followed by a gradual fall later. The variability in this strain bears resemblance to that observed by Ayyar and Rao [1930] in the case of another *indicum* cotton, N 14. The variation in Co 1 also corresponds with that found by them except in the last position. Armstrong and Bennett [1933] also have noted an increase of length up to about the middle of the lock with a fall later. Sen [1932], however, does not find any significant difference.

It is clear from the foregoing that in some strains definite differences do exist among the positions in a lock. In breeding work, where the halo length is measured on a few seeds only, it becomes imperative that the effect of this factor, which is considerable, is to be eliminated. Hence the seeds of a definite position in the lock have to be selected.

(*b*) *Fibre weight*

The results for this property which were obtained for the different group-lengths for the various positions have been studied by the method of analysis of variance. The variance values are given in the appendix and the mean values* are given in Table XII.

TABLE XII

Fibre weight per cm. in 10^{-6} *gm.*

Position of seed	Co 1	Co 2	K 546
Pedicel end—			
I	2·16	2·17	2·67
II	2·06	2·05	2·50
III	1·99	1·99	2·33
IV	2·01	1·98	2·32
V	1·97	1·98	2·20
VI	1·98	2·01	2·24
VII	2·04	2·02	2·19
VIII	2·05	1·98	. .
IX	1·97	2·07	. .
Stigmatic end—			
Critical difference for $P = 0\cdot 05$.	0·043	0·046	0·047

The first position has the highest weight in all the three strains. The variations among the other positions are not considerable in Co 1 and Co 2, while in K 546 there appears to be a steady fall with advance of position. The difference between the extreme values is 8 per cent in the Cambodias, while it is 18 per cent in K 546. Sen [1932] also finds the lowest weight in the stigmatic end and highest at the pedicel end.

The variance table (appendix) shows that for Co 1 and Co 2 the variance between positions accounts for a small portion of the total, while for K 546 it accounts for a good deal. All variances are, however, significant for the one per cent level of significance. The critical difference calculated both according to the residual and interaction errors denoted that many differences for K 546 and some for Co 1 and Co 2 are significant.

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* The arithmetic means got in the analysis of variance are given here in place of the weighted means. But this does not modify any of the conclusions drawn, as very little difference was found to exist between the two means.

(*c*) *Unit fibre weight*

The values are given in Table XIII.

TABLE XIII

Unit fibre weight in 10^{-6} *gm.*

Position of seed	Co 1	Co 2	K 546
Pedicel end—			
I	5·54	5·53	6·58
II	5·29	5·18	6·35
III	5·12	5·13	6·15
IV	5·18	5·00	6·06
V	5·10	5·08	5·67
VI	5·15	5·26	5·68
VII	5·31	5·30	5·33
VIII	5·34	5·17	..
IX	5·02	5·44	..
Stigmatic end—			

In Co 1 and Co 2 there does not appear to be much variation, except that the first seed records the highest weight. In K 546 there is almost a steady fall with the advance of position.

(*d*) *Number of fibres per seed*

The values are given in Table XIV.

TABLE XIV

Number of fibres per seed

Position of seed	Co 1	Co 2	K 546
Pedicel end—			
I	12,890	15,040	3,990
II	14,250	16,270	4,220
III	14,000	15,370	3,870
IV	13,640	15,910	3,770
V	13,810	15,300	3,490
VI	13,640	14,810	3,320
VII	13,240	14,220	3,300
VIII	12,680	13,170	..
IX	13,270	12,340	..
Stigmatic end—			

In all the three strains, after a preliminary rise from the first to the second position there is a continuous fall towards the end of the lock. The trend of variation, however, is not so marked in Co 1 as in the other two strains.

(*e*) *Number of fibres per unit area of the seed*

The figures obtained by dividing the number of fibres got above by the surface area found previously are given in Table XV.

TABLE XV

Number of fibres per unit area of the seed surface, in arbitrary units

Position of seed	Co 1 ($\times 1/k$)	Co 2 ($\times 1/k^1$)	K 546 ($\times 1/k^1$)
Pedicel end—			
I	7,530	8,750	4,990
II	7,830	8,790	5,020
III	7,650	8,440	4,660
IV	7,750	8,510	4,710
V	7,680	8,230	4,360
VI	7,550	7,970	4,150
VII	7,320	7,860	4,070
VIII	7,040	7,180	..
IX	7,250	7,020	..
Stigmatic end—			

The trend of variation appears to be nearly parallel to that found in the case of the total number of fibres on the whole seed, except that the divergences noted between the first and second positions are levelled up and the fall is more continuous. It, therefore, follows that the variations observed are more due to the density of the fibre population than to the surface area.

(*f*) *Immaturity*

As in the case of the fibre weight, these results were also studied by the method of analysis of variance. The variances are given in the appendix and the mean values in Table XVI.

The absence of results for some of the positions acts as a handicap against drawing definite conclusions in strains Co 2 and K 546. In Co 1 for which results for all the positions are available, no regular trend of variation is apparent.

The variances are significant in all the strains, for all the three types of fibres. The interaction variance is also significant in almost all cases, indicating the existence of a differential response of position of seed to causing immaturity among the different lengths of fibres.

TABLE XVI

Maturity percentage

Position of seed	Ripe fibres			Dead fibres			Thin-walled fibres		
	Co 1	Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 546
Pedicel end—									
I	72·6	...	...	11·6	...	...	15·8	...	...
II	78·8	61·7	...	8·4	17·8	...	12·8	20·6	...
III	71·1	...	79·2	12·2	...	11·0	16·7	...	9·8
IV	68·5	51·2	85·7	11·9	33·9	8·3	19·6	14·9	6·0
V	59·7	...	75·5	21·0	...	14·9	19·3	...	9·6
VI	64·4	55·9	...	17·7	25·0	...	17·9	19·1	...
VII	69·0	...	80·4	12·4	...	10·7	18·6	...	8·9
VIII	66·4	59·6	...	16·8	20·5	...	16·9	19·9	...
IX	66·2	...	...	11·7	...	...	22·1	...	...
Stigmatic end—									
Critical difference for P = 0·05	2·8	3·2	2·9	2·4	3·6	1·8	2·5	3·2	2·4

INTER-RELATIONSHIPS

The data obtained may be utilized for the study of the inter-relationships among the several characters. This knowledge will enable us to get a better insight into the factors governing the lint index and ginning percentage among seeds developing under conditions obtaining in a lock, where the influences of soil, weather, age of plant, etc. do not enter.

The study of the correlation coefficient is the method adopted. It should, however, be pointed out, at the outset, that the application of this method to the present case is open to the objection that the variables do not satisfy one of the three conditions essential in the simple sampling of attributes. As the seeds are situated within a lock, the individual values of any character are not completely independent of one another. Again, if the interpretation of the correlation coefficient is to be correct, the regression lines must be proved to be linear. As the number of pairs of values (nine for Co 1 and Co 2 and seven for K 546) are small the test of linearity will be of doubtful significance. Hence the conclusions that can possibly be drawn from the values of the correlation coefficient should be taken, at best, as approximate indices showing the general trend of association only. The values of the coefficients are given in Table XVII.

Taking the seed weight first and comparing it with its components, the embryo weight and seed-coat weight, it is seen that the association * in both cases is positive, showing that the growth of the whole is consequent on the growth of both the parts. The area of seed surface, the number of fibres produced on the seed, the density of the fibre population (except in Co 1) and the lint weight (also excepting in Co 1) are also found to be positively associated.

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* By association is meant that the two properties vary in the same direction though the correlation coefficient may not be significant.

The lint weight was stated above to be positively associated with the seed weight. The association with its components may now be considered. Whereas with the embryo weight the association is negative in Co 1 and Co 2 and positive in K 546 (all not significant), the correlation coefficient of the lint weight with the seed-coat weight is positive in all the three cottons and significant in two of them. This means that the lint and seed-coat follow a similar line of development which is different from that followed by the embryo.

Comparing the lint weight with its own component parts, it is found to be associated to a greater extent with the number of fibres per seed than with the unit fibre weight in the Cambodia strains, while in K 546 it is equally associated with both. Coming to the further sub-divisions of the whole fibre, it is found that there is hardly any association except for two cases—in K 546 the lint weight is positively and significantly correlated with the weight per unit length and in Co 2 it is similarly but negatively correlated with the length of the fibre.

The association of the ginning percentage with the seed weight is found to be negative in Co 2 but positive in the other two cottons. But it has been found by previous workers that, as a general rule, a higher ginning percentage is associated with lower seed weight. Turner [1929, 2] from his own data as well as that got from Balls comes to this conclusion. Dunlavy [1933] and Kearney [1926] report likewise, the values of the correlation coefficient obtained by them being —0·53 and —0·43 respectively. Griffee *et al.* [1929] got —0·112 as the value of the correlation coefficient in 18 American Upland varieties. Among the seeds in a lock, however, this does not appear to be the case. In only two cases out of the 25 cottons is the association negative. In five of them the correlation coefficient is significantly positive and in one of them highly so.

The ginning percentage is positively related to the number of fibres per seed and the association is still better with the density of the fibre population on the seed. This is in agreement with the statement of Balls [1930], 'whatever minor factors may be involved that the major determinant of the ginning out-turn is the number of hairs per seed.' Higher out-turn is also associated with the better development of the fibre., viz. fibre weight per cm.

Taking the unit fibre weight and its components, it is found to be highly related to the weight per unit length, having almost nothing to do with the length of the fibre.

CONCLUSIONS

(1) The mean fibre length is nearly constant in Co 1. In Co 2 it rise gradually from the first position to the last, while in K 546 it rises up to about the middle of the lock and falls later on.

(2) The fibre weight per cm. does not indicate any variation in Co 1 and Co 2, except for a higher value in the first position. But a consistent fall from first to last position is noted in K 546.

(3) The unit fibre weight shows no variation in Co 1 and Co 2, but exhibits a gradual fall in K 546.

(4) The number of fibres per seed as well as the number per unit area gradually decreases towards the end of the lock. The rise noted from the first to the second position in the former character is absent in the latter.

TABLE

Correlation

Properties correlated	Lint weight			Ginning percentages			Embryo weight			Seed-coat weight			Fibre
	Co 1	Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 54	Co 1
Seed weight . . .	—·28	+·60	+·77	—·60	+·47	+·74	+·82	+·45	+·66	+·32	+·71	+·79	+·52
Lint weight . . .				+·76	+·87	+·83	—·34	—·37	+·46	+·45	+·83	+·77	—·19
Ginning percentage .							—·68	—·46	+·42	+·02	+·78	+·76	—·39
Embryo weight . .										+·39	—·36	+·70	+·53
Seed-coat weight . .													+·20
Fibre length . .													
Fibre weight . . .													
Number of fibres . .													
Unit-fibre weight . .													
Area													

Value for significance ($P = 0{\cdot}05$) is 0·67

XVII

coefficients

length		Fibre weight per unit length			No. of fibres			Unit fibre weight			Area			No. of fibres / area		
Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 546	Co 1	Co 2	K 546
—·31	+·36	— 71	—·16	+·57	+·27	+·71	+·78	—·58	—·39	+·73	+·42	+·41	+·43	+·04	+·56	+ 77
—·76	+·07	+·25	+·33	+·77	+·63	+·84	+·84	+·24	—·10	+·81	—·08	+·05	+·41	+·74	+·88	+·85
—·78	+·05	+·55	+·42	+·78	+·32	+·79	+·84	+·50	—·05	+·81	+·28	+·02	+·43	+·51	+·87	+·85
+·59	+·56	—·66	—·71	+·11	+·01	—·19	+·55	—·52	—·42	+·31	+·59	+·49	+·52	—·02	—·42	+·49
—·73	+·27	—·49	+·20	+·55	+·71	+·83	+·81	—·41	—·26	+·64	+·26	+·33	+·60	+·63	+·83	+·76
		—·32	—·44	+·26	—·37	—·71	+·09	—·08	+·10	+·02	—·14	+·04	+·08	—·34	—·79	+·08
					+·17	+·06	+·71	+·85	+·72	+·80	—·69	—·66	+·21	—·04	+·31	+·75
								—·44	—·45	+·76	+·39	—·21	+·51	+·76	+·84	+·84
											—·62	—·77	+·22	—·11	—·17	+·80
														—·11	+·11	+·35

for Co 1 and Co 2 and 0·75 for K 546.

(5) The variation in the maturity cannot be assessed definitely on account of the absence of complete data.

(6) A study of the inter-relationships among the different characters discloses the following points :—

(*a*) The seed weight is positively associated with many of the characters, reflecting the general trend of all-round growth.

(*b*) The lint weight is more prominently associated with the number of fibres per seed than with the weight of the whole fibre in both Co 1 and Co 2. In K 546, however, it is equally associated with both.

(*c*) The ginning percentage is strongly associated with the lint weight. The negative correlation of the ginning percentage with seed weight, generally reported by different workers among different varieties, is not confirmed in the present case among seeds within a lock.

(*d*) The unit fibre weight is more dependent on the weight per unit length than on the length of the fibre.

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REFERENCES

Abraham, P. and Ayyar, V. R. (1937). *First conference of scientific workers on cotton in India, 1937*, p. 371

Armstrong, G. M. and Bennett, C. J. (1933). *J. agric. Res.* **47**, 447-76

Ayyar, V. R. and Rao, C. J. (1930). *agric. J. India* **25**, 42-52

Balls, W. L. (1930). *Min. Agric. Egypt Tech. and Sci. Bull.* No. **101**, 15

Dunlavy, H. (1923). *J. Amer. Soc. Agron.* **15**, 444-8

Griffee, F. *et al.* (1929). *Oklahama Expt. Sta. Bull.* **187**

Iyengar, R. L. N. (1929). *Madras Agric. Dept. Yearbook, 1929*, 7-15

Iyengar, R. L. N. and Turner, A. J. (1930). *Ind. Cent. Cot. Com., Tech. Lab. Tech. Bull. Ser. B.* No. **7**

Iyengar, R. L. N. (1939). *Indian J. agric. Sci.* **9**, 305-29

Kearney, T. H. (1926). *J. agric. Res.* **33**, 781-96

Sen, K. R. (1932). *Indian J. agric. Sci.* **2**, 484-98

Turner, A. J. (1929, 1). *agric. J. India* **24**, 83-90

Turner, A. J. (1929, 2). *Ind. Cent. Cot. Com. Tech. Lab., Tech. Bull. Ser. B* No. **4**

APPENDIX

Analysis of variance

Property	Cotton	Variance due to	Degrees of freedom	Mean square
Fibre weight per cm. in 10^{-6} gm.	Co 1	Positions	8	0·1500*
		Lengths	4	1·4310*
		Residual	315	0·00416
	Co 2	Positions	8	0·1560*
		Lengths	4	1·9818*
		Residual	315	0·00503
	K 546	Positions	6	1·2458*
		Lengths	4	0·4553*
		Residual	245	0·00572
Ripe fibres percentage	Co 1	Positions	8	1461·63*
		Lengths	4	1886·18*
		Residual	405	25·84
	Co 2	Positions	3	636·60*
		Lengths	4	915·96*
		Residual	100	20·64
	K 546	Positions	3	622·77*
		Lengths	4	3772·60*
		Residual	120	19·91
Dead fibres percentage	Co 1	Positions	8	766·13*
		Lengths	4	409·26*
		Residual	405	17·41
	Co 2	Positions	3	1493·40*
		Lengths	4	702·06*
		Residual	100	25·05
	K 546	Positions	3	261·22*
		Lengths	4	2212·84*
		Residual	120	7·65
Thin-walled fibres percentage	Co 1	Positions	8	347·75*
		Lengths	4	582·53*
		Residual	405	19·73
	Co 2	Positions	3	196·30*
		Lengths	4	92·94*
		Residual	100	20·00
	K 546	Positions	3	108·38*
		Lengths	4	237·58*
		Residual	120	12·00

* Significant for $P = 0{\cdot}01$

STUDIES ON PROPAGATION OF THE MANGO, *MANGIFERA INDICA* L.

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(With Plates XXXVIII and XXXIX)

INARCHING in the case of superior varieties and seed propagation in the case of others have been the commonest mango nursery practices in India for centuries. Of late, a number of workers in India have experimented upon the possibility of raising mangoes by other vegetative methods, chiefly by shield budding. Owing partly to regional variations in regard to climate and cultural practices and partly to the relatively small-scale trials or the unsystematic nature of these trials, the published results of such investigations are either scarce or inconclusive, and the extent of success obtained has been very varying, and generally poor.

Inarching, though easy in practice, is a more expensive method than budding, and according to some workers [Fielden and Garner, 1936] is only suitable for countries where labour is cheap. It has also been asserted that trees propagated by inarching are often short-lived or stunted—results which are being now attributed to the operation of inarching itself instead of to the cutting off of the tap-root as was formerly believed [Fielden and Garner, 1936]. According to Paul and Guneratnam [1937] budded plants have proved to be more vigorous in growth than inarched or cleft-grafted plants in Ceylon. Above all, inarching can only be performed at reasonable cost where scion parent is growing in the close vicinity of the nursery, whereas budding, side-grafting and such other vegetative methods are possible even with scion wood obtained from a distance. Widespread use of vegetative methods other than inarching is therefore desirable for a variety of reasons.

Popenoe [1927] has recorded that it is not a simple matter to bud mangoes successfully and adds that only a few propagators in the United States of America are able to produce budded mango trees economically and in quality. Woodrow [1904] made many attempts in India to bud mango, but without any success. After some trials in Poona, Burns and Prayag [1906] came to the conclusion that 'mango budding is yet an uncertain means of propagation'. They also refer to the report of similar lack of success from the trials in Saharanpur and Nagpur. Higgins [1906] and Paul and his associates [1937] were, however, able to obtain a high success by budding in Hawaian Islands and Ceylon respectively, while in Porto Rico [Popenoe, 1927] crown-grafting was found to be more successful than budding. In Java nearly 90 per cent success is reported for the modified Forkert method of budding [Fielden and Garner, 1936]. Wray [1939] reports to have top-worked in

Jamaica over 1,000 mango trees by budding, but he does not mention the extent of success obtained.

Among methods of vegetative propagation other than budding and inarching which have recently merited attention in so far as mango is concerned, side-grafting and mound layering through ringing of etiolated shoots are the most important. Success by side-tongue grafting has been reported from Hawaii [Fielden and Garner, 1936] and by ordinary side-grafting with pre-cured scions by Nakamura [Tanaka, 1939]. Fielden and Garner [1936] quoting the experiments in Java consider it possible to raise rootstock seedlings vegetatively by ring-barking and eticlating the ringed parts so as to induce rooting therein. Whip grafting, saddle grafting, wedge grafting, embryo grafting, rooting of cuttings, and marcotting have also been tried with little or no success in different lands, but none of these has had a wide application in commercial nursery practice [Fielden and Garner, 1936]. The available results from these trials afford justification for the hope that some of these methods at least may be so improved in technique as to render it possible to replace in a large measure the prevalent practices of mango propagation by seed and inarching. It is on these grounds that further research on most of the above-mentioned various propagational methods in an important mango-producing province as that of Madras is justified.

On the basis of the work of a number of people, Hatton [1932] has proved that seedling rootstock in mono-embryonic fruits furnishes a very variable material. Where rootstocks cannot be raised vegetatively, polyembryony has been shown to be a great advantage in securing uniform rootstocks from seed [Hatton, 1932, Fielden and Garner, 1936]. Popenoe [1927] has surmised that although the seedling races of the tropics are polyembryonic in character, most of the grafted Indian varieties have lost this characteristic and seedlings from these differ from their parents as does a seedling peach. On the authority of Belling, Fielden and Garner [1936] have pointed out that broadly speaking, the choice mangoes of the East Indies and Philippines are polyembryonic, while the Indian varieties are mono-embryonic, and the former reproduce themselves true from seed to such a remarkable extent that it may be assumed that the fertilized embryo is often absent. Sen and Mallik [1940] have found that multiple shoots with only a single tap-root occur occasionally in the germinating seeds of Bombai, Langra and Fazli varieties of mangoes in Bihar. Such observations have formed the common experience of nurserymen in South India as well, and may have given rise to the erroneous belief entertained by some that most of the cultivated mangoes of India are polyembryonic. The discovery of polyembryonic mangoes for obtaining a pure line of vegetatively produced descendants to serve as uniform seedling rootstock, as is being done in citrus [Hatton, 1932], instead of the variable material from mono-embryonic mango varieties as is done at present in India is, therefore, a work of considerable scientific and practical importance.

After a very comprehensive review of literature on root-stock and scion relationship, Swarbrick [1930] infers that the 'stem-piece of the rootstock may have as much influence in determining what is known as "rootstock influence" as the actual absorbing root-system'. He refers to the earlier work of Roberts and himself in the United States of America and the conclusion arrived at from their investigations [1927] that a large amount of the uniformity obtained by the use of vegetatively propagated rootstocks is in the first place due to selection, and in the second to the use—in effect—of a uniform intermediate stem-piece. Swarbrick concludes that 'greater uniformity of tree growth and performance would be obtained by eliminating such stem pieces when grafting seedlings'. He also adds that 'greater uniformity should result from double-working, particularly if the first working takes the form of bench grafting on to root pieces'. Knight [1927] and Grubb [1925] have also shown that the stem-piece of a rootstock was an important item in the ultimate effect of rootstock upon scion. Bench-grafting which is popular in the United States of America and is also becoming popular in England and Australia [Whittaker, 1940] is supposed by Swarbrick [1930] to eliminate all stem influence but that of the scion itself. He adds that 'there is no validity in the *a priori* assumption that use of miscellaneous seedlings will give miscellaneous results', and that, 'the claims of the seedling rootstock deserve the same systematic attention and investigation that is being given to the vegetatively propagated rootstocks'. The mango rootstock which is only seed-propagated in India does not therefore require a stronger plea than the above for its demand on the attention of the workers in this country. Since vegetative methods of propagation of mango rootstock have not so far been successfully devised at least to an extent as to warrant their adoption on a commercial scale in mango nursery trade, and since according to Swarbrick [1930] great uniformity in seedling rootstocks can be obtained by the elimination of stem-piece of the rootstock in the budded or grafted plant, the need for exploring the value of employing only the root-piece of the seedling rootstock in mono-embryonic mangoes of India will not require over-emphasis.

The investigations reported in the present paper were designed to determine firstly, the optimum season and technique for mango propagation by the prevalent methods of inarching in due regard to the regional requirements, secondly, to discover one or more methods of vegetative propagation which can advantageously replace the commonly adopted method of inarching, thirdly, to find out if any polyembryonic mangoes exist in this part of India and, if so, what their value as rootstocks to superior cultivated mango varieties are, and fourthly, to explore the possibility of imparting uniformity to seedling rootstocks from mono-embryonic parents through root-grafting and double-working on the lines advotcated by Swarbrick [1930].

EXPERIMENTAL

The experiments reported in these pages were initiated in 1935 and were in progress thereafter for a period of about five years. As they comprised of several independent investigations, and facilities could not become available for undertaking of all these at one time, the actual period of work on each independent problem, as will be shown later, has varied greatly, depending upon the facilities and the importance of the investigation. For these reasons and for the sake of clarity, it is considered appropriate to present the report on each propagational method separately along with the materials and methods under each.

POLYEMBRYONY

The district of Malabar claims the largest acreage under mangoes in the Madras province. Almost the entire mango crop in this district is produced by seedling trees, and despite this fact, the produce is believed to be remarkably uniform to an extent met with in vegetatively propagated orchards. Some of the seedling trees in this district and in the neighbouring tracts of South Kanara have also enjoyed the reputation of being very precocious, producing crops within three or four years of sowing. These facts led to the belief that most of the mangoes grown in these regions may be polyembryonic, and this assumption was further strengthened from the reports received from some of the growers and agricultural departmental workers in the West Coast, chiefly from Mr E. K. Govindan Nambiar, Farm Manager of Talliparamba Agricultural Research Station.

In view of the great importance and value of polyembryonic mangoes in the work of standardization of seedling rootstocks and of the difficulties encountered all over the world in the vegetative propagation of rootstocks, a study of these South Indian mangoes for testing their polyembryonic character was thought necessary. Accordingly, during the mango season in 1937, 246 seeds from 11 trees of apparently eight different races of polyembryonic mangoes were collected in the West Coast and sown in the nurseries of the Fruit Research Station, Kodur. The seedlings were lifted and potted during the following October, and a careful and detailed count of the number of seedlings obtained from each seed was made.

The total number of seedlings obtained out of the 129 germinated seeds were 218, and the maximum number of seedlings got from one seed were four in Kurkan and Olour varieties. These preliminary observations were sufficient to establish clearly the polyembryonic character of these West Coast mangoes. Incidentally, it was observed that after potting of these seedlings, the casualties amounted to only seven seedlings. This fact not only strengthens the polyembryonic character of these races, but also indicates that transplanting of these mango seedlings with naked roots, necessitated by detailed examination of their polyembryonic character, is a feasible nursery operation.

A fresh collection of seed material was made during the mango season in 1938 in the course of a tour in the West Coast. As a result, 1,024 stones of ten apparently different polyembryonic varieties were collected and sown at Kodur during April and May 1939, and 800 stones of five of these varieties were also supplied to Horticultural Research Station, Sabour (Bihar), for study there.

The seedlings obtained from the material sown in 1939 at Kodur were lifted and potted during September 1939. The data recorded from an examination of these seedlings on that occasion are tabulated in Table I.

It is observed that the maximum number of seedlings obtained per seed has been as many as five in Kurkan No. 2 variety, and four in Bellary, Olour, Kurkan No. 1, and Goa. On the basis of seedling count on germinated seeds, it is found that Kurkan No. 1 and 2 appear to be most highly polyembryonic and Muvandan the least, excluding, however, the mixed lot from Calicut.

TABLE I

Actual number of seedings obtained from 10 different varieties of polyembryonic mangoes during 1939

Variety	No. of stones sown	No. of seeds from which the seedlings obtained were at the rate of					Total No. of seedlings obtained	Ratio seedlings / germinated seeds	Percentage of germination	Seedlings as per cent of seeds sown
		One each	Two each	Three each	Four each	Five each				
1. Neelaparanky . .	97	10	12	5	...	...	49	1·8	27·8	50·5
2. Bellary	100	27	17	11	5	...	114	1·9	60·0	114·0
3. Olour . . .	90	12	7	3	1	...	39	1·7	25·6	43·3
4. Mylipelian . . .	116	44	14	6	...	...	90	1·4	55·2	77·6
5. Chandrakaran . .	24	12	4	...	...	...	20	1·3	66·7	83·3
6. Muvandan . . .	21	5	1	...	...	...	7	1·2	28·6	33·3
7. Mixture of Salen, Kumbran and Neelaparanky from Calicut	184	15	1	...	...	...	17	1·1	8·7	9·2
8. Kurkan, K-1	75	4	5	3	1	...	27	2·1	17·3	36·0
9. Kurkan, K-2	95	10	14	6	...	1	61	2·0	32·6	64·2
10. Goa	205	33	18	8	5	...	113	1·8	31·2	55·1

It is commonly believed that polyembryonic mangoes, in general, give very poor germination. This statement is probably true in most of the varieties tested, but it certainly does not hold good in Bellary, Chandrakaran and Mylipelian varieties. If the actual number of seedlings obtained are taken into consideration, it will be seen that Kurkan No. 1, Muvandan and Olour are perhaps the only varieties which are not likely to appeal to the mango nurserymen, and Bellary would be the most favoured.

SEED PROPAGATION

A. Method of sowing

It is known to mango nurserymen in India that a varying number of mango seedlings possess crooked stems which render them unfit for use as rootstocks for inarching. For the purpose of root-grafting also (a method which will be described elsewhere) it is essential that the rootstock seedling should have a straight piece of tap-root close to the collar. It is observed that the mango seedling in the initial process of its emergence through the soil is susceptible to make a detour when the least impediment occurs by way of a small gravel or any other solid piece in the soil above the seed in the path of the growth and emergence of the seedling out of the soil. In most cases, it is also found that a loop is formed on the stem of the young seedling as a result of the difficulty experienced at the time of emergence of the growing tip from the seed shell. This difficulty may not be met with when shelled stones are sown. If the growing tip succeeds in extricating itself at an early stage, the stem distortion is slight and such stems may gradually become straight later on (Plate XXXVIII, fig. 1). Where the emergence is delayed the seedling stems may continue to be crooked so as to render them unfit for inarching. While maintenance of a good soil tilth may certainly minimize the number of seedlings with defective stems, the method of treatment of seeds and of sowing, which are believed to be the chief contributory factors, require also to be attended to.

To throw more light on the above questions, 765 mango stones were sown in 1937 by 10 different methods. Of these, 405 stones were shelled and the remaining 360 were sown unshelled. Each of these two lots was sown by five different methods in almost equal numbers as under :—

(*a*) stones sown with plumule pointing upwards ;
(*b*) stones sown flat on the sides ;
(*c*) stones sown with suture upwards ;
(*d*) stones sown with suture downwards ;
(*e*) stones sown with plumule pointing downwards.

All these methods are illustrated in Plate XXXVIII, fig. 1 in so far as unshelled stones are concerned. In Plate XXXVIII, fig. 2, a typical seedling obtained from the shelled stone sown with plumule up is also shown alongside the seedling from unshelled stone sown by the same method. A close examination of the root and stem portions of the typical specimens shown in these figures as well as the observations made on all the seedlings show that :—

(*a*) sowing the mango stones with plumule up produces a straight taproot and stem, both of which characters facilitate inarching and root-grafting operations ;

(*b*) sowing the stones by any of the other four methods tested, induces a crooked formation of the tap-root and stem of the resulting seed lings, the degree of crookedness occurring roughly in the following descending order of magnitude in these four methods : (1) stones flat, (2) stones with suture up, (3) stones with suture down, and (4) stones with plumule down and

(*c*) shelled stones produce a straighter tap-root and stem than unshelled stones, but the germination percentage in the former group has been found to be very much lower than in the latter.

For convenience of root-grafting and inarching operations as also for all other methods of vegetative propagation, sowing of unshelled stones with plumule up offers, therefore, greater advantages than the prevalent method of sowing the unshelled stones flat.

The practice of shelling the stones before sowing would seem to be preferable from these data to the sowing of unshelled stones in so far as the production of straight-stemmed seedlings are concerned, and also for an effective elimination of diseased or worm-infested kernels. The shelled stones also were found to germinate on an average 12 days earlier than unshelled stones in the above experiment. But the germination in the former was less by about 14 per cent than the latter. In view of the expensiveness of shelling operation and the cheapness of mango stones, it s therefore doubtful if Indian nursery trade will resort to shelling on a commiercial scale, despite certain advantages associated with it.

B. Grading of stones in relation to germination percentage

During the 1936 mango season, 6,713 fruits were collected from seven seedling trees, and the fruits were graded into three different groups according to size. The stones extracted from each of these three grades were again graded according to the size of stones into three sub-groups. The germination percentage of each of these are set forth in Table II.

It is apparent from these figures that large-sized fruits have not invariably given a higher percentage of germination in all the progenies. As regards the effect of grading stones on germination, the differences between the various groups are also contradictory, although small stones from smallest-sized fruits have generally accounted for the lowest germination percentage. The diflerence between the grades is not in any way larger than that noticed between seed parents ; for instance between 5/1 ad 0/6. It is, therefore, doudtful if grading of fruits or stones can be classedns a necessary operation in mango nursery practice in view of the contradictory results or the small differences between the various groups or sub-groups.

C, Vigour and measure of variability in mango seedlings

Height and girth records of each of the 3,819 seedlings raised under the preceding experiment were collected on two different occasions, once during the second week of August 1936, and again during the second week of the following November. The coefficient of variability was calculated on the basis of these measurements. The concerned data relating to the stem diameter measurments collected during the second week of November 1940 are only presented in Tables III and IV.

The inferences drawn from these, however, appear to hold good in the case of the data collected on previous occasion also, both in respect of height and stem diameter measurements.

It is observed from these data that the vigour of seedlings from different parents differs to a certain extent. Tree No. 5/1, for instance, has produced in general a larger-sized batch of seedlings than tree Nos. 83 and 5/6.

The coefficient of variability ranges from 12·30 to 39·81 in respect of height measurements and from 14·79 to 64·57 in terms of stem thickness.

It appears that vigour of seedlings is not influenced to any appreciable extent by the size of fruit or stone in the case of progenies raised from seedling mango trees. It is, however, possible that the inherent vigour of the seed parent is a dominating factor masking all possible influences, as those of fruit or stone size, on the vigour of seedlings.

During the 1938 season, about 27,000 stones from 29 different seedling trees were sown in separate beds for raising seedling rootstocks. This large collection of seedlings exhibited, at a very early stage of their growth, pronounced differences between the progenies in the matter of size. In order to gather information on the extent of differences in seedling size between the various progenies, height and girth measurements of the individual seedlings of 11 different progenies sown in June 1938 were collected in April 1939. The analyses of these measurements showed that the mean height ranged from 29·93 cm. to 62·80 cm. and the mean girth from 0·50 cm. to 1·08 cm. Tree No. 0/4 produced within a period of about nine months from sowing the largest-sized seedlings suitable for use as rootstock for inarching or budding operations. This, in effect, means a saving of considerable time and expenditure to the nurserymen during the pre-inarching period, if the progeny of this tree is preferred to others as rootstocks and if this progeny continues to maintain its superiority over others in future also.

D. Transplantation and watering of seedlings

It is the universal practice in this country to retain a ball of earth around the roots of mango seedlings at the time of their transplantation. It has been previously pointed out that during the examination of the root of some polyembryonic mango seedlings in 1937, it was found feasible to transplant some seedlings with naked roots also. To confirm these observations a separate trial was initiated in the same year. It was found from this trial that, out of 129 seedlings of about 6 months' of age transplanted with naked roots on 11 January 1937, 82·9 per cent survived, as against 86·9 per cent success obtained by transplanting seedlings of the same age and on the same date with a ball of earth having an average diameter of 6 in. at the collar. In both the batches, the roots were shortened to nine inches from the ground-level and the seedlings were transplanted into nursery beds under the shade of an old mango tope. It is apparent, therefore, that the exposure of roots for a short duration at the time of transplanting is not detrimental to the life of the mango seedlings, under conditions existing at this station and in the seasons in which the trials were carried out.

It will be shown later under root-grafting trials that the above inferences are amply corroborated by the data collected in some other independent trials also.

TABLE

Germination percentage of mango stones of 7 seed parents graded

(Seeds sown from May to July

Tree No.	Big fruits						Medium fruits			
	Big stones		Medium stones		Small stones		Big stones		Medium stones	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
5/1 . . .	57	87·7	95	81·1	67	79·1	66	84·8	87	65·5
83 . . .	70	75·7	100	65·0	164	50·0	129	76·7	160	68·1
0/2 . . .	230	69·1	170	67·6	94	46·8	238	63·0	240	62·9
2/3 . . .	163	55·2	90	55·6	40	40·0	36	55·6	40	42·5
1/2 . . .	123	61·0	110	50·9	66	47·0	152	52·6	114	8·51
0/6 . . .	215	45·1	114	35·1	33	45·5	154	62·9	175	29·8
5/6 . . .	55	65·4	75	77·3	32	68·8	88	47·3	114	55·1

II

according to size of fruits and stones prior to sowing

1936 soon after extraction)

		Small fruits							
Small stones		Big stones		Medium stones		Small stones		Average weight of fruits (oz.)	Average weight of stones (oz.)
No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent		
83	61·4	71	81·7	66	48·5	64	67·2	Big . . 4·31 Medium . 3·12 Small . 3·02	Big . . 0·85 Medium . 0·78 Small . 0·71
148	56·1	77	57·1	100	51·0	96	32·3	Big . . 3·05 Medium . 2·86 Small . 2·42	Big . . 0·62 Medium . 0·57 Small . 0·57
191	50·8	45	64·4	73	61·4	84	26·2	Big . . 3·89 Medium . 3·16 Small . 3·01	Big . . 0·86 Medium . 0·83 Small . 0·74
30	43·3	55	52·7	62	43·5	60	41·7	Big . . 3·52 Medium . 3·05 Small . 2·88	Big . . 0·63 Medium . 0·59 Small . 0·57
84	51·2	90	38·9	91	·6	167	43·1	Big . . 3·76 Medium . 3·51 Small . 3·12	Big . . 0·62 Medium . 0·57 Small . 0·48
82	28·1	128	37·5	249	12·9	262	10·4	Big . . 4·62 Medium . 3·97 Small . 3·92	Big . . 0·74 Medium . 0·69 Small . 0·63
96	75·0	72	48·9	113	50·1	144	42·2	Big . . 3·44 Medium . 3·22 Small . 3·01	Big . . 0·59 Medium . 0·54 Small . 0·50

TABLE

Average height of mango seedlings

Tree No.	Big fruits						Medium		
	Big stones		Medium stones		Small stones		Big stones		Medium
	Height cm.	C*	Height cm.	C	Height cm.	C	Height cm.	C	Height cm.
5/1	34·49	31·62	34·30	22·91	41·02	25·12	36·42	19·50	45·16
88	25·90	26·30	23·33	27·54	19·48	30·20	24·18	26·92	21·89
0/2	24·36	25·12	26·03	24·55	35·55	38·90	20·61	25·70	18·90
2/3	26·42	21·88	26·98	17·78	27·26	12·30	29·49	16·60	29·24
1/2	26·46	27·54	29·37	25·12	23·12	27·54	24·58	28·18	23·14
0/6	25·42	24·55	24·41	27·54	20·92	36·31	24·18	28·84	22·24
5/6	21·32	30·90	17·97	25·12	17·58	30·90	20·25	28·84	19·45

TABLE

Average diameter of mango seedlings at 3 cm.

Tree No.	Big fruits						Medium		
	Big stones		Medium stones		Small stones		Big stones		Medium
	Diameter cm.	C*	Diameter cm.	C	Diameter cm.	C	Diameter cm.	C	Diameter cm.
5/1	0·66	27·54	0·58	26·30	0·58	33·88	0·44	64·57	0·60
88	0·51	23·99	0·45	25·70	0·39	26·92	0·46	21·88	0·48
0/2	0·44	32·36	0·47	25·70	0·40	27·54	0·38	28·84	0·40
2/3	0·38	42·66	0·47	20·42	0·48	14·79	0·50	18·20	0·46
1/2	0·45	24·55	0·53	22·91	0·43	22·91	0·45	54·95	0·42
0/6	0·51	17·38	0·47	26·30	0·47	15·14	0·38	52·48	0·45
5/6	0·40	22·39	0·37	22·91	0·38	16·22	0·39	22·91	0·37

C—Coefficient of variability

III

and their measure of variability

fruits			Small fruits					
stones	Small stones		Big stones		Medium stones		Small stones	
C	Height cm.	C	Height cm.	C	Height cm.	C	Height cm.	C
21·38	37·17	26·30	32·38	25·12	28·66	30·90	33·45	26·92
30·20	24·19	39·81	19·96	26·92	21·18	29·51	18·26	31·62
28·18	19·63	28·84	19·22	28·84	18·91	29·51	16·35	26·92
14·79	25·39	15·49	27·58	19·95	26·45	18·20	26·15	25·12
23·99	21·87	24·55	22·99	23·44	25·63	21·38	23 05	28·18
20·89	23•27	19·05	21·40	22·39	22·68	28·18	17·11	26·92
25·70	17·98	25·70	18·28	20·89	15·66	39·81	17·43	26·30

IV

above ground-level and their measure of variability

fruits			Small fruits					
stones	Small stones		Big stones		Medium stones		Small stones	
C	Diameter cm.	C	Diameter cm.	C	Diameter cm.	C	Diameter cm.	C
29·51	0·63	19·95	0·54	25·70	0·51	23 44	0·61	25·12
28·18	0·37	29·51	0·38	25·12	0·37	27·54	0·41	25·70
27·54	0·35	33·88	0·36	25·12	0·34	29·51	0·26	18·20
16·98	0·40	17·78	0·46	23·99	0·41	23·44	0·43	23·99
23·99	0.39	16·22	0·44	30·20	0·49	19·50	0·43	28·18
21·38	0·47	16·60	0·42	20·42	0·38	26·30	0·31	33·88
20·89	0·34	38·90	0·35	26·92	0·33	25·70	0·72	58·88

Subsequently, in 1939-40 a series of trials were carried out with a varying number of seedlings to test the efficacy of lifting seedlings and potting them after partial defoliation. It was found from these trials that lifting mango seedlings for potting seven to nine days after heavy defoliation, when only a couple of leaves in the terminal rosette are retained, reduces the mortality of such seedlings to the minimum extent possible even during hot and dry periods of the year.

From a different series of rough trials it was also found that, as against the common practice in South India of watering the potted mango seedlings daily, the irrigation interval can be extended to three to five days, depending upon the weather conditions, if the potted seedlings are kept close together in a trench and water is let in in a manner to fill the trench up to the edge of the pots. The latter practice is said to be fairly well known in parts of Bombay province and deserves to be adopted in other parts of the country as well.

INARCHING

A. Age of rootstock seedlings for inarching

During 1935-36, 1,056 seedlings of different ages were used for inarching, mainly to raise the requisite number of grafts for planting in the variety collection plot. From these it became clear that inarching of young seedlings of even 4½ months of age could be done successfully. A take of 62·5 per cent was obtained in one lot of 192 seedlings of 4½ months of age inarched in February 1936. Paul and Guneratnam [1937] have stated that stocks between six months and one year old give more vigorous and earlier-bearing plants when grafted or budded. It was not possible to study at Kodur the orchard performance of grafts on very young rootstocks. Till this is done, it will not be possible to recommend their use in commercial mango culture.

However, with the available facilities a small trial was initiated during February 1937 to ascertain the effect of seedling rootstocks with ages ranging from 7½ to 16½ months at the time of inarching. A total number of 1,365 stones from a single seedling tree were sown on 17 June 1936, for the purpose of this trial, after grading the stones according to three different sizes. Of the seedlings obtained from the largest-sized stones, 100 seedlings which were apparently most uniform in growth and vigour were selected for the purpose of this trial and these were potted on 6 January 1937. These seedlings were inarched to selected scion shoots from a single Neelum tree in batches of 25 each on four different occasions at intervals of three months each, by a single operator. The grafts in every case were separated exactly four months after the date of inarching. The girth measurements of the rootstocks at the time of potting as well as on 27 March 1938 were collected and recorded. Similar records were intended to be collected once a year after planting of the finally selected grafts in the orchard site.

Table V summarizes the records collected prior to the final planting of the trees.

The data in the table do not render it possible to draw any definite inferences. However, the increased girth measurements recorded in the earlier inarched batches is a point worth mentioning.

TABLE V

Records of Neelum grafts on rootstocks of different ages

Rootstock parent—Country 0/2, F. R. S. ; Scion parent—Neelum (57 C. R. Garden)

Serial No.	**Age of the rootstock at the time of grafting**	Date of in-arching (1937)	Date of sepa-ration (1937)	Percent-age take	Mean girth of the stock at 1 in. below the union on 27 March 1937 in cm.	Mean girth of the scion at 1 in. above the union on 27 March 1937 in cm.
1	**7½ months** . . .	2 Feb. .	2 June .	96	4·05	3·52
2	**10½ months** . . .	2 May .	1 Sept. .	92	3·45	2·6
3	**13½ months** . . .	2 Aug. .	2 Dec. .	92	2·86	2·23
4	**16½months** . . .	2 Nov. .	2 Mar. .	92	2·98	2·33

The selected grafts were planted out on 31 December 1939 in a separate plot according to the lay-out approved by the Statistician to the Imperial Council of Agricultural Research, New Delhi. The details of the material used other than those already furnished above and the method of lay-out are shown below :—

Plot size	40 ft. × 120 ft. (0·11 acre)
Number of plants in each plot . . .	3
Spacing	40 ft. square
Number of replications	4
Performances of the scion parent . .	1936—50 to 100 fruits 1937—25 to 50 fruits 1938—Over 100 fruits
Treatments	A—Neelum on rootstocks of 10½ months of age while planting B—Neelum on rootstocks of 13½ months of age while planting C—Neelum on rootstocks of 16½ months of age while planting

The girth and height measurements of each of the 36 Neelum grafts, as collected at the time of planting, when analysed, have shown that there is no significant difference between the three batches of grafts either in regard to the height or girth measurements. This seems to falsify the popular belief that older the rootstocks the greater the size of the grafts in the plantation.

Similar measurements were collected on 8 June 1940, i.e. 18 months after planting. These data also when analysed statistically have failed to show any significant differences between the three treatments. Selection of Neelum grafts on older rootstocks would therefore appear to be not an advantageous practice at least within the age limits included under this trial and from the point of view of growth performance of the trees within the first 18 months of planting.

B. Season for inarching

In order to gather an idea regarding the optimum period for inarching of the most important commercial varieties of mangoes in this tract, an experiment was planned out in the beginning of 1936. Two Neelum trees and two trees of Bangalora were selected every month as scion parents foı this purpose in a neighbouring plantation. All these had reached their full bearing age, having been planted about 20 years prior to the commencement of this trial.

Every month 100 grafts were prepared at the rate of 25 on each tree or 50 in each variety. Two months after this operation, the first cut was given to the seedling rootstock and the scion followed by the second cut after three months, and the final separation of the grafts was effected four months after the date of inarching. The grafting was done by two independent operators, one tree of each variety having been allotted to one operator every month. The age of the seedling rootstocks used in different months differed to a certain extent, as it is bound to be in a crop wherein fresh seeds become available for sowing only in a short period of the year. In spite of the aforesaid unavoidable vitiating factors, the results obtained are considered to be of sufficient practical importance.

The analysis of variance worked out for the results of all the 12 months is presented in Table VI.

TABLE VI

Analysis of variance

Serial No.	Due to	Degrees of freedom	Sum of squares of deviations	Mean square	Significance
1	Varieties . . .	1	1065·97	1065·97	$P<$ 0·05, significant
2	Months . . .	11	14115·71	1283·25	$P<$ 0·01, very significant
3	Operators . . .	1	231·54	231·54	$P>$ 0·05, not significant
4	Interaction of varieties to months	11	1090·04	99·09	Not significant
5	Interaction of varieties to operator	1	13·13	13·13	
6	Interaction of operator to months	11	1583·67	143·97	
7	Error	11	1266·88	115·17	
	Total .	47	19366·94	412·06	

S. E. of differences between means for varieties= 3·10

S. E. of differences between means for operators= 3·10

S. E. of differences between means for months= 7·89

Critical difference for varieties= 6·82

Critical difference for months= 22·57

The mean percentage take for each month and for each variety is presented in Table VII.

TABLE VII

Mean percentage take in each month and for each variety

Varieties	Percentage take in each month (1936-37)												General mean per cent
	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
Neelum .	88	69	52	100	100	94	64	94	98	98	96	98	87·6
Bangalora .	78	74	20	88	96	96	64	76	88	82	86	90	78·2
Average .	83	72	36	94	98	95	64	85	93	90	91	94	...

The efficiency of take during the several months is arranged in descending order as follows :—

Aug. Sept. July March Dec. Feb. Jan. Nov. April May Oct. June

(The treatments under or above the same bar do not significantly differ from each other.)

The greatest efficiency is got in the months of August, September, July, March, December, February and January followed by November and April. May and October are next in order, while June is the worst month. It is seen that, on the whole, Neelum contributes to a greater success by the process of inarching than Bangalora, and the difference between the two varieties, namely 9·4 per cent, is statistically significant. It is also evident that there has been no significant difference between the operators.

The take recorded in the above experiment does not wholly tally with that obtained in a separate trial during 1937 with Neelum scion (Table V). In the latter case, inarching in February has contributed the maximum take, while no difference is noticed between the take recorded in May, August and November. On the other hand, in the former trial, although the take in Neelum plants inarched in February is identical with that obtained in the latter trial and the take in plants inarched in November 1936 and 1937 are nearly so, a slightly higher figure is noted in plants inarched in August 1936, and a very much smaller figure in plants inarched in May 1936 than in those inarched in the corresponding months in 1937. These differences are easily accounted for by the variation in weather conditions from year to year and also in the age of the seedling rootstocks.

C. Separation of grafts

Ordinarily all grafts are separated out by the nurserymen from the scion parents about three months after the inarching operation in this tract. But a noticeably large number of casualties occurred during 1937 and 1939 in Rumani variety soon after separation of the grafts after the above period, although no such ill-effects were observed in the case of Neelum and Bangalora grafts. Consequently during 1939-40, the separation of grafts of Rumani from the scion parent was delayed by a month with obvious benefit. It seems clear from these observations that different varieties demand different lengths of time from inarching to separation stage, and in case of Rumanis at least a four-month period is essential, even though an equally high success can be got in Neelum and Bangalora with a three-month period.

D. Treatment of grafts after separation

A preliminary trial to test the efficacy of the prevalent practice of nursing the grafts for some time immediately after separation from scion parent was carried out on three different occasions during 1939-40, using 24 grafts four at each time. The results show that the grafts can be depotted and planted successfully in their permanent orchard sites, immediately after separation from the scion parent and after four months from the date of inarching, during November-February. Such treatments as those referred to in the preceding sentence were responsible for an earlier manifestation of 'flush' than in the case of grafts kept in pots under shade for nursing after separation. The difference in the time taken to flush between the batches of grafts planted soon after separation and those kept under shade was 87 days in the case of grafts separated in the beginning of November, while in the grafts separated out and planted at the end of December and end of January, the number of days taken to flush were 77 and 69 respectively, as against no flush in the comparable batches of grafts kept under shade until the end of the year under report.

It is known that there is a wide dissimilarity in the fruit nursery trade in India in regard to the period of nursing the grafts after separation. While several nurserymen in South India often sell grafts almost immediately after separation, in other parts of the country it is believed that the grafts should be nursed at least for four months after separation. The above-stated results, relating as they do to a few grafts prepared and nursed with special care, may not therefore provide a safe guide for widespread application.

ROOT-GRAFTING

Since no commercially successful method of vegetative reproduction of mango rootstocks has yet been devised, some means of obtaining uniform material with a miscellaneous seedling basis is found necessary to render accurate field trials on mangoes possible. It has already been pointed out by other workers that a stem-piece of the rootstock often masks and outweighs the influence of the absorbing root-system and, therefore, if only the root-piece of the seedling rootstock is grafted to the scion thus eliminating the stem influence of the rootstock, it should be possible to obtain a uniform material for the purpose of field trials. The success of the method will depend upon the ability of the mango seedlings to withstand exposure of root during the root-grafting operation, the ease with which the root-piece can be grafted to the scion, and perhaps also the season of operation and the age of rootstock and scion.

With a view to elucidating these various problems, a number of preliminary trials were laid out during 1936. One of these was intended to ascertain the most suitable method of making the maximum number of potted seeding rootstocks available with about three inches of root-piece exposed for the root-grafting operations.

The following three methods were tested in this connection :—

(*a*) Lifting seedlings direct from open nursery beds and transplanting them into beds under shade and again re-lifting these with naked roots and potting them with about 3 in. of root-piece exposed.

(*b*) Lifting seedlings from the nursery beds with naked roots and potting them, and again transferring them after a period to fresh pots with about 3 in. of root piece exposed near the collar.

(*c*) Lifting seedlings direct from open nursery beds and potting them with about 3 in. of root-piece exposed near the collar.

The plants used in the experiment were those the seeds of which were sown in April 1936. The primary lifting in (*a*) was done in January 1937 and in (*b*) in December 1936. While potting the seedlings finally, care was taken to keep the seedling close to the edge of the pot to facilitate the grafting operation. A further device which subsequently proved very useful was also adopted, and this consisted of making a U-shaped notch, 1 in. wide and 2 in. long, close to the edge of the pot. The exposed root-piece of 3 in. long was made to project out through this notch.

The final potting was done every month commencing from May 1937 in the case of method (*b*). In the case of (*a*), the final potting was done every month from May to December 1937. In method (*c*), the final potting was done only twice, viz. May and July 1937 and was not repeated subsequently as none of the plants survived the treatment.

In every trial, the number of seedlings selected for the final potting operation in these preliminary trials was 12, and the same operator was responsible for the lifting and potting operation in all the three methods.

The percentage of survivals in method (*a*) was roughly 50 in May, 16·7 in July, 25 in October and nil in other months, while in method (*b*), it was about 75 in May, September and October, between 50 and 75 in July, November, December and January, between 25 and 50 in June and February and less than 25 in August. Method (*c*), as has already been stated, failed to produce any success.

The above figures show that method (*b*) has invariably proved the most suitable and, further, that September, October and May were the three optimum months during 1937-38 for this treatment. It is of considerable interest to note that, contrary to the existing belief that mangoes do not transplant well without a ball of earth around the root, over 50 per cent survivals were obtained by method (*b*) on seven months and about 75 per cent in three out of ten months for which the results are available.

Side by side with the above trials, preliminary investigations were initiated to find out the most suitable method and season for the root-grafting operations. At the outset, it was found that root-grafting of the seedlings, immediately after they were lifted from the open beds with naked roots and potted, failed to give much success as only two out of eight in May 1937 and none out of the same number in July 1937 showed successful takes.

Among those lifted and potted as per method (*b*) described above and root-grafted immediately after final potting in 1937, the number of successful takes obtained out of eight in each month have been five in those grafted in May, two in June, none in July, three in August, none in September, one in October and three in November.

In the case of seedlings lifted and potted by method (*a*) and root-grafted immediately after final potting, the number of successful takes obtained out of eight grafted every month in 1937 have been nil in those worked in May, two in June, three in July, four in August, nil in September, one in October and nil in November.

On the other hand, among the seedlings which were finally potted after various treatments and root-grafted after about a month's hardening, the percentage take has been 40 in those grafted in May, 60 in June, 22 in July, 100 in August, 30 in September, 38 in October, 17 in December, 50 in January and 33 in February.

Since the number of plants root-grafted in the various months is small, it will be idle to draw any valid inferences from the above figures. It is, however, possible to state from these preliminary trials that root-grafting is an operation which is feasible in mangoes (Plate XXXIX, figs. 1-3). The figures also indicate the possibility of raising a sufficiently large number of mango root-grafts with ease for the purpose of initiating accurate field trials. Further trials are no doubt called for to ascertain the optimum season for root-grafting operation, and these were undertaken on an elaborate scale during the following year. The question of the best method of planting root-grafts in the orchard site without any damage to the tender parts of the graft-joint by irrigation required also to be investigated, and this was also attended to during 1937 and 1938. None of the 15 root-grafts planted in these two years showed the least sign of damage to the graft-joint after a year of planting. This preliminary observation was considered sufficient for the time being to enable the raising of a larger plantation of root-grafts for further field tests.

Accordingly, 900 mango seedlings from one mono-embryonic seed parent were lifted with naked roots and potted in November 1938, four months after sowing in seed-beds. Of these, only 44 or about 5 per cent died soon after potting, while 81 seedlings suffered to a varying extent as a result of these operations. The low mortality, or in other words, the high percentage of survivals in these seedlings again confirms the previously recorded results, that mango seedlings can be lifted successfully with naked roots in commercial nursery practice.

During February 1939, 610 good seedlings were selected from the above-mentioned batch of potted seedlings and were re-potted for root-grafting purposes into U-notched pots, exposing 2-2½ inches of tap-root near the collar. A very much larger number of casualties occurred in this re-potting operation than during the first potting period. The seedlings that finally survived were root-grafted to two selected trees of Neelum and one of Bangalora in July 1939. The details of the success obtained are set forth in Table VIII.

The above operations were carried out along with some inarching, double-working, cleft-grafting, side-grafting and budding trials under similar and uniform conditions. But the data relating to other methods are not presented here. However, it is observed from the data in Table VIII that root-grafting operation performed in July 1939 has been responsible for a very high take. If allowance is made for the large mortality of seedlings during the re-potting operation, it would, however, be found that this propagational method compares very unfavourably with inarching. In order to present a comparative idea of the actual number of plants finally obtained from every

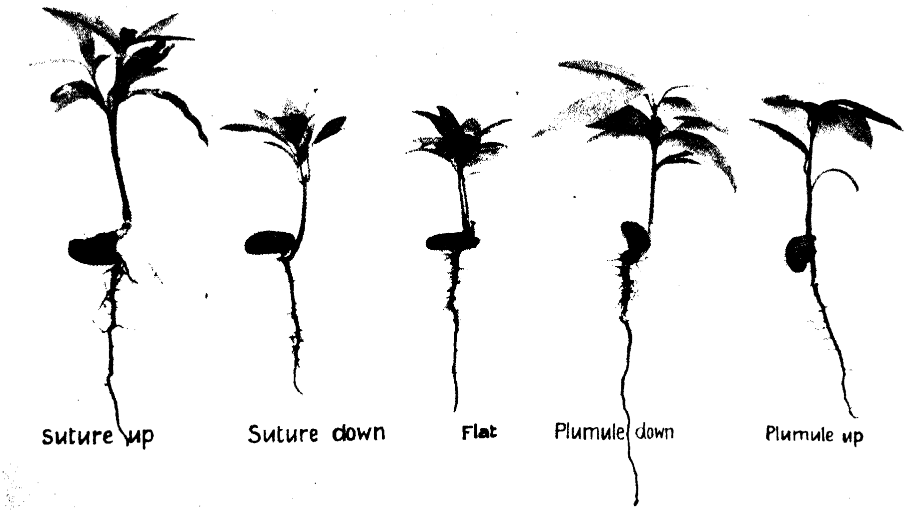

Fig. 1. Var. Country, unshelled stones : D. S.=31.7.37 ; D. Ex.=15.12.37

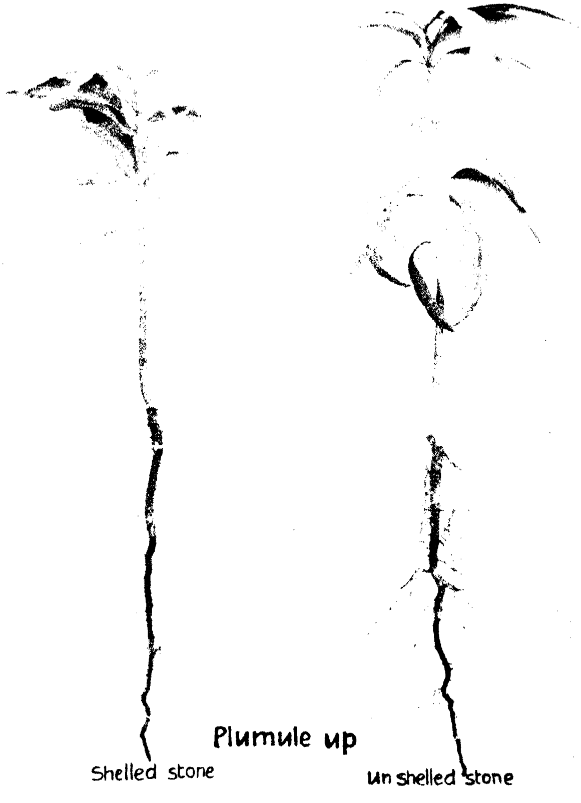

Fig. 2. Var. Country : D. S.=31.7.37 ; D. Ex. 15.12.37

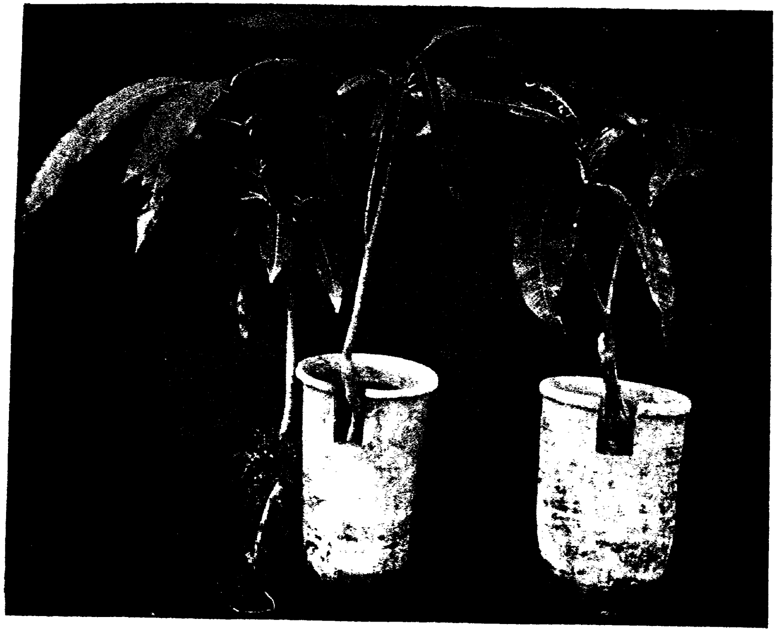

FIG. 1. Mango seedling soon after lifting, with naked roots

FIG. 2. The same potted with about 2½ in. of root near the collar protruding out of U—notch

FIG. 3. A root graft ready for planting out

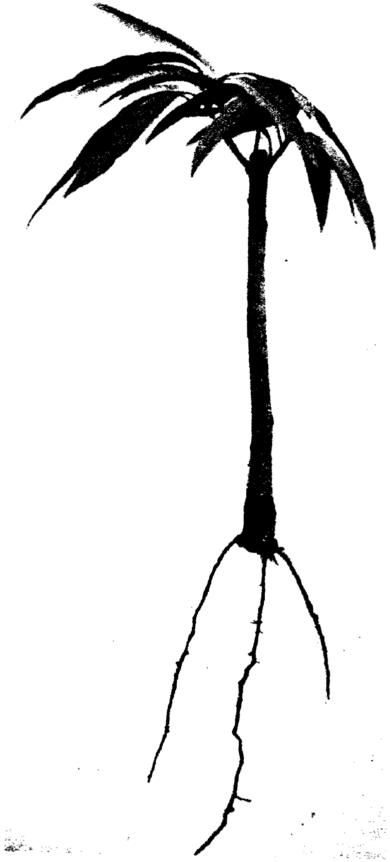

FIG. 4. Mango cutting: S=3.7.36; R=23.7.37; P=22.9.37; Sp=16.10.37; Ex.=26.11.37

100 seedlings originally selected in seed-beds for the purpose of the various propagational methods included under one comparative trial, the following figures are presented.

TABLE VIII

Details of success from mango root-grafting trials, 1938-39

(Seed parent—7/1 F. R. S.)

Serial No.	Propagation method and scion parent	Number grafted	Date of grafting (1939)	Date of separation (1939)	Percentage take
1	Root-grafting—Neelum 1st scion parent	72	11 July .	31 October	97·22
2	Root-grafting—Neelum 2nd scion parent	16	14 July .	Do. .	93·75
3	Root-grafting—Bangalora 1st scion parent	88	8 July .	Do. .	95·45

Propagational method and scion variety	Percentage of grafts obtained from the orginally selected seedlings
Root-grafts of Neelum	23·81
Root-grafts of Bangalora	23·39
Double-grafts of Neelum	54·11
Double-grafts of Bangalora	71·94
Inarched plants of Neelum	84·42
Inarched plants of Bangalora	90·00
Shield-budded plants of Neelum	71·06
Patch-budded plants of Neelum	67·57
Shield-budded plants of Bangalora	21·84
Patch-budded plants of Bangalora . . .	8·58
Cleft-grafted plants of Neelum	0·85
Cleft-grafted plants of Bangalora . . .	0·85

Despite its low efficiency in comparison with inarching, double-working and budding with one scion variety, it is obvious that root-grafting is a feasible nursery practice in an ever-green tropical fruit like mango.

BUDDING

A rough preliminary trial on the budding of mangoes was first initiated at Fruit Research Station, Kodur, in June 1937. Six different methods of budding were tried with 48 seedlings of about 12 months of age growing in open nursery beds. The methods followed are briefly described below :—

Method 1 : A transverse incision was made in the bark of the seedling rootstock as far as the cambium and the bark was then peeled down up to a length of about 1½ in. after making two vertical parallel cuts connecting the two ends of the transverse cut. The peeling has to be done carefully so that it may come out in one strip. The bud-shield was removed in the same manner as in oranges with a small piece of wood attached to it, and this was pushed under the flap till all the exposed edges of stock rind and bud-shield were in perfect contact. In order to do this, the size of the bud-stick is required to be the same as that of the stock stem. The flap was brought into position and made to cover the bud-shield completely. The covered bud was then wrapped around with paraffined cloth and finally by a piece of dried banana sheaths. This method is almost similar to that described by Paul and Guneratnam [1937].

Method 2 : This method is identical with the chip budding described by Fielden and Garner [1936], except that no sealing of the cut surface was done in these trials. The buds were wrapped around with paraffined cloth strips.

Method 3 : This is exactly the method of 'invert-T' budding or the shield method employed for budding citrus plants. The bud was inserted with a piece of wood attached o the bud-shield.

Method 4 : This method resembles the modified Forkert method described by Fielden and Garner [1936]. The bud-shield inserted in this method also had a piece of wood attached to it and paraffined cloth was also wrapped around the bud.

Method 5 : This resembles the patch budding described by Fielden and Garner [1936]. The width of the bud-shield was about an inch. The bud was wrapped round the stock after insertion with raffia fibre, and over this by paraffined cloth.

Method 6 : This method is practically similar to method No. 5 and is designated as modified patch-budding or flute-budding by Fielden and Garner [1936]. The wrapping of the bud after insertion was done in a similar manner as described in the preceding method.

In all these cases, the paraffined cloth, raffia or banana sheath coverings were removed three to four weeks after bud-insertion. The flaps of bark were also cut off wherever they had been retained if the buds were found green at this time, and the rootstock seedling was ringed about an inch wide and about two inches above the point of insertion in order to stimulate the growth of bud-sprouts. After the bud-sprouts had sufficiently matured, as was indicated by the dark green colour of leaves, the rootstocks were lopped off above the point of bud-insertion.

A month after insertion, it was observed that 37 buds out of 48 were green and alive, of which the largest number was in the batch budded by method No. 1 and least in the plants worked by method No. 3. Analyses of the finally available bud-sprouts after 3 months of insertion, however, showed that method No. 2 did not produce a single take, methods Nos. 3-6 were responsible for a take of only one or two in each, while method No. 1 produced the highest successful take of five out of eight insertions.

In a separate trial, 24 'petioled' and 24 'unpetioled' buds of one scion variety were inserted by these six methods in July 1937. The 'petioled' buds are those which are inserted with a portion of the petiole attached to the bud-shield. In the case of 'unpetioled' buds, however, the leaves of the selected bud sticks are completely removed, wherever they are found, about a fortnight before the actual insertion. The petiole is absent in the bud-shield and the scar caused by the defoliation is healed by the time of insertion, and in some instances the dormant bud is also slightly stimulated into activity. The number of successful budded plants out of these 48 insertions amounted to 21, petioled buds accounting for 11 of these successful takes, and method Nos. 2 and 5 showing the lowest takes of one each.

In addition to these trials which were carried out in open nursery beds, 24 seedlings in pots were budded in June and July 1937 by the above-mentioned six methods. Unlike in the open beds, the success obtained in these potted seedlings has been very poor, only two plants in June and one in July

1937 having shown a successful take. It is possible that the relatively slow growth of rootstocks in pots hinders the successful take of mango buds.

The only possible inference that could be drawn from these small preliminary trials was that in the open beds budding of mangoes offers a good chance of becoming an established nursery practice.

Owing to the unexpected death of trained mango budder, it was not possible to undertake a comprehensive trial on budding of mangoes during the following year. However, a number of persons were given training in various methods of budding, and a total number of 643 buds were inserted at different times of that year. In the October (1937) insertions, one of the budders under training was able to obtain 50 per cent take, which is considered to be a fairly good index of the skill of the operator as well as a good indication of the possibility of budding in commercial nursery practice.

During 1939-40, a series of budding trials were again conducted, once along with some side-grafting trials, and again along with a number of other propagational methods. In the former case, it was intended to compare side-grafting, using terminal scion shoots, with patch-budding in respect of two scion varieties, viz. Alfonso and Erramulgoa. The lay-out of this trial consisted of four replications for each of the four treatments with 18 seedlings per plot or 72 per treatment. The treatments were randomized within the blocks. A single operator was employed in this trial also. The operations were done from 22 to 25 August 1939, when the days were very windy, dry and warm. The summary of the results is presented in Table IX.

TABLE IX

Mango side-grafting and patch-budding trials showing the summary of result regarding the take of scions

	Erramulgoa patch budding (A)	Alfonso side-graftng (B)	Erramulgoa side-grafting (C)	Alfonso patch budding (D)	General mean	S. E. D. mean	Level of significance	Critical difference
Mean take per treatment (per cent)	61·11	48·61	38·39	16·67	41·32	12·38	$P=0·05$ $P=0·01$	27·64 39·75
Mean take as per cent of general mean	147·89	117·64	94·12	40·34	100·00	29·60	$P=0·05$ $P=0·01$	66·89 96·20

Conclusions: Erramulgoa patch-budding Alfonso side-grafting Erramulgoa side-grafting Alfonso patch-budding

(Treatments under or above the same bar do not differ significantly from each other)

The very large difference noticed between the two varieties in Table IX in regard to the take of buds strongly indicates that different mango varieties respond differently to this method of mango propagation.

In the second comparative trial conducted in 1939-40, shield (method No. 3) and patch method (method No. 1) of budding were only employed. Neelum and Bangalora were selected as scion parents and tree No. 7/1 from the Station tope was used as second parent. The seeds were sown on 26 June 1938, and the seedlings were transplanted into fresh nursery beds on 25 February 1939. The germination percentage recorded in these was 50 and the percentage of success in transplantation 85. The success obtained is shown in Table X.

TABLE X

Success from budding of mango in 1939

Serial No.	Method of budding	Scion variety	Date of budding	Number budded	Percentage take
1	Shield . . .	Neelum .	4 July 1939	73	83·56
2	Patch . . .	Do. .	7 July 1939	73	79·45
3	Shield . . .	Bangalora	8 July 1939	140	25·70
4	Do. . . .	Do. .	Sept. 1939	21	23·80
5	Patch . . .	Do. .	Do. .	24	8·30
6	Shield . . .	Do. .	Oct. 1939 .	30	13·30
7	Do. . . .	Do. .	March 1940	25	20·00

The wide differences between the takes of buds of Neelum and Bangalora strongly confirm the previous recorded inference that certain mango varieties respond better to this method of propagation than others. From investigations conducted thus far with four different varieties, it is clear that Neelum and Erramulgoa have proved at this Station to be most suitable for propagation by budding during July-August, while Bangalora and Alfonso have proved relatively unsuitable.

Between shield and patch methods of budding as tried during the year under review, the former has contributed a slightly higher success than the latter, but the difference is too small to vest the former method with any great importance.

SIDE-GRAFTING

At the suggestion of the Agricultural Commissioner with the Government of India, trials on side-grafting of mangoes as advocated by Nakamura [Tanaka, 1939] were undertaken during 1939. At the outset, 27 seedlings were utilized in July 1939 by one budder for gaining sufficient practice with this operation. An unexpectedly high take amounting to 92·59 per cent obtained in this lot indicated the necessity for carrying out more comprehensive trials with this method of propagation.

In one series of trials laid out subsequently, 26 Neelum and 26 Bangalora soft-wood scions from the apical region of the shoot were selected during an intermittent rest period between two cyclic growths and these were precured according to the method suggested by Nakamura [Tanaka, 1939] before side-grafting them to 52 one-year-old seedlings on 4 and 5 August 1939 by one single operator.

The percentage take in these batches was found to be 92·31 in Neelum and 88·46 in Bangalora, of which 76·93 per cent of the scions in the former and 53·85 per cent in the latter variety had sprouted and were in active growth within 26 days after the operation. Closer examination of the materials used for this trial revealed that all the failures were restricted to those scions which had a diameter of less than 0·5 cm. each. It was also found that scions that are likely to fail, shrivel within a week after the operation, and those that are likely to take will have a number of ant visitors. The latter observation is in conformity with those recorded by Tanaka [1939]. It was also noticed that several well-developed scions started into active growth within about 10 days after the operation in this month, while Nakamura [Tanaka, 1939] noticed such a phenomenon only 22 days after insertion.

The comparative trial with side-grafting and budding has already been reported (Table IX) under the preceding subject of budding.

In a small but independent trial, 72 scions of Alfonso from the mid-portions of the shoots and a similar number of shield-buds of the same variety were inserted during September 1939 in nursery beds, and these have registered a take of 23·6 per cent and 27·8 per cent respectively. The inferior value of mid-portions of scion shoots is therefore indicated.

It has been previously shown that terminal scion shoots of less than 0·5 cm. diameter are relatively less suitable for side-grafting in mangoes. In order to verify this inference, the scions used for the comparative trial on budding and side-grafting (Table IX) were classified according to their diameter measurements and the figures of take of each of these classes are presented in Table XI.

TABLE XI

Analyses of take according to scion diameter measurements

(Mango side-grafting trials)

Variety	Scion diameter	Percentage take
Alfonso	Above 0·5 cm.	93·55
	0·5 cm. and below	41·18
Erramulgoa	Above 0·5 cm.	79·17
	0·5 cm. and below	36·00

These figures again confirm the previously recorded inference that scions of less than 0·5 cm. diameter are of little value for mango propagation by side-grafting.

The above inferences are further borne out from the observations recorded from a separate trial with Bangalora and Neelum scions side-grafted in September 1939 in nursery beds. With thicker scions, the former variety has produced a take of 65·5 per cent and the latter 70·0 per cent, while with thinner scions of 0·5 cm. diameter and less, the take has been 24·0 per cent and 41·7 per cent, respectively. It is therefore seen that thinner scions have to be definitely discountenanced. It would also seem that certain varieties respond to this method of propagation to a much better degree than others.

The results of the side-grafting trials in July and August in the nursery beds were so encouraging that it was considered desirable to investigate the possibility of this propagational method with seedlings grown in pots. Trials were accordingly carried out for a period of four months commencing from August 1939. A total number of 373 scions of different varieties were inserted towards the end of August or early in September 1939, another batch of 193 scions was inserted in October 1939 and a third batch of 42 scions was inserted in November 1939. The analyses of take in these various batches consisting of scions of different varieties are given in Table XII.

TABLE XII

Analyses of take from the rough mango side-grafting trials in pots from August to November 1939

Month	Percentage of take			
	Terminal scion with diameter of over 0.5 cm.	Terminal scion with diameter of 0.5 cm. or below	Mid-portion of scion shoot with diameter of over 0.5 cm.	Mid-portion of scion shoot with diameter of 0.5 cm. or below
August-September 1939	68.8	28.5	19.4	10.7
October 1939 .	31.9	9.5	Nil	Nil
November 1939 .	Nil	Nil	Nil	Nil

These results further confirm the value of thicker scions having a diameter measurement of over 0·5 cm. in side-grafting operations. They also show that the take with terminal parts of the scion shoot is very much higher than with the lower or mid-portions of the same scion shoots. The failure of all scion shoots side-grafted in November as well as the extremely low take recorded in October are attributed to the heavy precipitation received during these months. More than half of the rainfall for the year, amounting to 18·76 inches, was recorded during these two months, when rains fell over a total number of 24 days. There seems to be, therefore, some evidence in support of the belief that rainy weather is not congenial for this operation. It is also obvious from the data obtained from the various trials that certain seasons are more suitable than others for side-grafting purposes.

Subsequent observations on the growth of the side-grafts have shown that the plants are extremely slow in producing elongation growth in pots, so much so, that none of the side-grafts worked from August to November in pots became ready for setting out in the field till March 1940, whereas some of the side-grafts raised in beds during July-August became ready for planting out within about 3½ months after side-grafting. It has, therefore, been found necessary to transplant all the side-grafts from pots into nursery beds, and this was done in March 1940.

Apart from the high take obtained by side-grafting in certain seasons, and the relatively cheapness of the operation, one special advantage associated with this method of propagation and budding is that it enables the raising of trees vegetatively even though the parent trees are situated at a distant place. A few plants have been successfully raised by side-grafting in November 1939 with scion wood obtained from Mayavaram and inserted at the Fruit Research Station, Kodur, after three to five days of separation from parent trees.

OTHER METHODS OF PROPAGATION

A. Double-working

Double-working being a necessary operation in top-working of grafted trees of inferior quality, a knowledge of the relationship between the various combinations of varieties used as rootstock, intermediate stem-piece, and ultimate scion is essential. Trials on double-working form also a natural complement to the trials on root-grafting, as double-worked root-grafts are believed to enjoy greater uniformity than the grafts on vegetatively propagated rootstocks.

Preliminary trials were, therefore, initiated in May 1937 and were continued till the following October. Every month, six grafts of Neelum and six of Bangalora were selected for this purpose, and these were double-grafted with scions of Bangalora and Neelum respectively. The results are shown in Table XIV.

TABLE XIV

Percentage of success in mango double-grafting from May to October 1937

Varieties Rootstock × Intermediate scion × Ultimate scion	Percentage of success					
	May	June	July	August	September	October
Country × Neelum × Bangalora . .	100·0	100·0	16·7	83·3	83·3	83·3
Country × Bangalora × Neelum . .	100·0	100·0	66·7	100·0	83·3	67·7

The number of individuals being small, the results have not been subjected to a statistical test. Nevertheless, the above figures clearly indicate that double-grafting is an easy operation and produces a very high success practically in all the months in which the trial was carried out. The reason for the low success in July 1937 in one set is, however, inexplicable.

The success obtained during 1939-40 by double-grafting with Neelum and Bangalora as ultimate scions has been mentioned previously while comparing this method with root-grafting. It was also brought out then that double-grafting is both an easy and convenient operation.

B. Cleft-grafting

As reported previously, this method gave only a take of 0·85 per cent in each with Neelum and Bangalora scions during 1939-40 trials. The trials were conducted in July 1939 on one-year-old seedlings, and 104 seedlings were utilized for cleft-grafting with each of the two scion varieties. From these it is concluded that cleft-grafting has proved almost a total failure at this Station.

C. Cuttings

During 1936, a large number of mango cuttings were planted in different seasons to find out if rooted mango cuttings can be successfully raised in this tract ; but the results were totally disappointing. In the following year a preliminary trial with 25 cinctured cuttings was initiated in September and October 1937 to test the rooting ability of such cuttings. Of these, six put forth fresh growth and three developed into vigorous rooted plants. Examination of one of these plants about four months after planting revealed, surprisingly, a fairly good root formation (Plate II, fig. 4).

In a separate trial, a total number of 592 cuttings from young and old trees ringed during nine successive months in 1937 were planted in nursery beds in order to collect observations on the influence of the age of the tree and the period of ringing and planting on the rooting of the cuttings. At the request of Messrs Imperial Chemical Industries, Ltd., 225 cuttings of mangoes were also planted in that year after dipping in Hortomone A, a proprietory product reported to be efficacious in inducing rooting. The planting of these cuttings for this trial was done in July 1937. None of the cuttings in these two trials rooted, although a few did show signs of growth activity for one or two months after planting only to wither away without forming any root-system. These trials were followed up by another in November 1938 with 250 cuttings of two mango varieties, ringed and planted two months after ringing operation and after treating some with anhydrous lanolin for 20 hours, some with 1/10,000 of B-indolyl acetic acid for 20 hours and some more with 1/20,000 of the last mentioned solution. Excepting for some evidence of the formation of root initials on four cuttings, none of these treatments has also indicated its usefulness for the purpose in view. It was, therefore, considered idle to pursue these trials any further.

D. Vegetative propagation of rootstocks

In order to determine the possibility of inducing the etiolated parts of mango plants to root and thus produce clonal rootstocks, 141 mango plants (72 seedlings and 69 grafts) were planted on different occasions from May to October 1937 in nursery beds and these were gradually pegged down and earthed up after they had fully established themselves in their new surroundings. As new shoots sprang up from these plants, they were etiolated and subsequently cinctured by tying around a thin piece of wire, and were again earthed up. None of the ten etiolated and cinctured shoots rooted up to the end of 1937, even though some were cinctured as early as August 1937. The method as followed, therefore, was not encouraging.

The combined practice of etiolating and cincturing, however, continued to be under trial during the following year with a view to ascertaining its suitability for raising mango rootstocks. As in the previous year, these methods proved to be totally disappointing, as not a single shoot out of the 20 etiolated and cinctured at two different periods of 1938 gave any evidence of new root formation.

PERFORMANCE OF TREES PROPAGATED BY DIFFERENT METHODS

In order to study the extent of uniformity in, and the orchard performance of, the plant material raised by some of the more important methods of propagation, an experiment was planned out in 1939. During the 1st and 2nd December 1939, 108 trees of apparently uniform size and vigour representing 18 root-grafts in each of Neelum and Bangalora, 18 inarched plants and 18 double-grafts in each of the same varieties were planted out in an area of 4·0 acres. The lay-out consisted of six replications or blocks with six treatments randomized in each, each plot of 20ft. × 120ft. being planted to three trees of each treatment. Twenty-two budded plants and nine side-grafts of Neelum from the same scion parent as that used in the above experiment, as well as six side-grafts of Bangalora also from the same scion parent as that used in the above trial, were planted out close to the above experimental area for general comparison of their performance with the trees included in the main experiment.

Growth measurements of all these experimental trees have been recorded at the time of planting and are proposed to be collected with other performance records every year in future. In order to ascertain if a variety like Neelum known to possess productive and regular bearing tendencies will transmit these desirable characters when used as an intermediate scion to a shy or irregular-bearing but choice-fruiting ultimate scion variety, and also to find out roughly the influence of double-working on precocity, tree size and tree performance, a small but separate observational trial with 28 double-worked mango trees was initiated in 1940. Four ultimate scion varieties, viz. Himayuddin, Jahangir, Allampur Baneshan and Mulgoa, have been included in this trial with Neelum as intermediate scion for all. The growth and performance of the trees in this trial plot are also being watched with interest.

DISCUSSION

The widespread commercial practice of raising grafted mango plantations in this country is due to the well-known fact that most of the Indian mangoes are mono-embryonic, and therefore their progenies are very variable. It has been proved from the present investigations that several polyembryonic mango races exist in the west coast of south India, and these should be able to transmit their characters to their progeny in a remarkable degree. Sen and Mallik [1940] have also corroborated the above findings, although these workers were not able to obtain as large a number of seedlings per seed from most of the South Indian polyembryonic races as at Kodur, possibly due to the delay in sowing of stones. Unfortunately, most of these polyembryonic races bear relatively inferior fruit and are consequently of little commercial importance. Nevertheless, they are of undoubted value as potential source of uniform rootstock material.

At present the Indian mango nursery trade is almost entirely dependent upon seedling rootstocks from mono-embryonic seed parents. The seedlings are being raised from fruits which are the result of open pollination. The pollen parent which plays an important part in determining the characteristics of the offspring being unknown, there is no knowing now to what extent good pollination and potent varieties are involved in the raising of our seedling rootstock material. The result is that our seedling rootstock is an admixture with widely differing growth and cropping potentialities. Tukey [1929] has emphasized on the necessity and importance of paying attention to selection of particular varieties as seed parents for raising seedlings of cherry, peach, apple and other temperate fruits for use as rootstocks. Indication has been afforded in the present studies also that considerable variation exists in regard to uniformity and vigour of seedlings raised from different seed parents. It would therefore be necessary to pursue the studies further so as to determine the most suitable mango varieties, races or individual trees as seed parents, and also to find out the most suitable or potent varieties as male parents for each selected seed mother parent or variety.

The removal of endocarp or hard seed-coat before planting of mango seed has been advocated by Kinman [1918] in order to increase the germination percentage and to reduce the time taken for germination. These results obtained in Porto Rico have recently been confirmed by Paul and Guneratnam [1937], who assert that it has become an established practice in laying down mango nurseries in Ceylon. The latter workers [Paul and Guneratnam, 1938] have also described a convenient method of extracting kernels. As shown earlier in this paper, although shelling has much to commend it, it is nevertheless a practice that is not likely to find favour in most parts of India. Mango seeds can be usually had at very cheap rates in most parts of this country, and the nurserymen will also be reluctant to bear the additional cost on the shelling operation. The lower germination percentage obtained from shelled stones at Kodur is also a point that has to be borne in mind in this connection.

Hoblyn [1931] has given examples to show how the trees on vegetatively raised rootstocks are more uniform than those on seedlings. Vegetative propagation of rootstocks by means of cuttings was found to be a failure by Burns and Prayag [1921], while by air-layering they found the percentage of success poor, root formation meagre and after-growth and fruiting of the layers very slow. Gootee or Marcottage was also tried by these workers with no better results. In Java, ring-barking of the shoots followed by covering the shoots with earth is reported to have caused rooting of the shoots [Fielden and Garner, 1936], while in the Federated Malaya States no root formation was secured. Leh [1930] reported that in Netherlands colonies, the vegetative propagation of mango is a puzzling question. In the trials conducted at Kodur, although some success was obtained by rooting of cuttings, the method is one that cannot be advocated at present in commercial nursery practice. Air-layering and Gootee methods being expensive and tedious were not tried, nor do the reports of other workers on the value of these methods are so encouraging as to be of any commercial value [Collins, 1903]. Ringing and etiolation methods were tried at Kodur during two successive years with a varying number of Neelum, Bangalora and seedling shoots with no success.

The work of elimination of the variability from seedling rootstock has therefore to be done through means other than vegetative propagation, among which the possibilities of the polyembryonic races as rootstocks are bound to be of considerable importance. Fielden and Garner [1936] state that the polyembryonic mangoes from East Indies and Philippines reproduce themselves true from seed to such a remarkable extent that it may be assumed that the fertilized embryo is often absent. This, if true, is a finding of very great value in excluding entirely the sexually originated seedling. Work has to be pursued further to see to what extent the above theory holds true in regard to the polyembryonic Indian races ; and if it is not true, to determine the possible methods of elimination of the sexual seedling. The rootstock value of each of our polyembryonic races is yet another fruitful line of study that needs to be intensified.

Apart from polyembryony, the value of root-grafting requires to be fully investigated as a means of removing the variability in the mono-embryonic seedling rootstock. Investigations in this line are already under way at the Fruit Research Station, Kodur, and the results when available are bound to be of interest to the workers on this fruit. Root-grafting may not have much value in commercial nursery practice, but its value for experimental purposes, particularly for the raising of uniform plant material on a miscellaneous seedling basis, cannot be denied.

In regard to the commercial methods of propagation of mango on seedling rootstocks, inarching has taken such a strong hold in this country that any other method may not easily appeal to the growers and nurserymen. The success in budding mango as reported in the present paper in certain seasons with certain scion varieties is, however, so very high that there seems little need for entertaining any further doubts about the possibilities of this method. But it is necessary to emphasize that, apart from the skill of the operator, the optimum season and the suitability of the scion varieties should first be determined before budding can be advocated on a large scale in any tract.

Side-grafting as recommended by Nakamura [Tanaka, 1939] is yet another method which can be advocated in commercial nursery practice, if the optimum season is first determined for each tract and for each variety. This method is even simpler in practice than budding and is found capable of giving an equally high take. It is being already employed successfully on a small scale for top-working larger trees in the west coast where humid atmospheric conditions prevail for a long period of the year. In drier tracts, as at Kodur, the method was found to be valueless for use in old trees, but with nursery trees, on the other hand, the method is full of possibilities if performed in a suitable season.

It is recognized that most of the investigations reported herein are not capable of furnishing information of a conclusive nature on all aspects of the problems under study. The number of questions to be elucidated was so large that considerations of economy imposed a necessity to undertake at the first instance a series of small-scale preliminary trials. The observations from these preliminary trials served as pointers for the lay-out of large-scale trials subsequently. If it is remembered that the success in any propagational method is governed by a vast array of factors, such as skill of operator, season of operation, age of the rootstock, size and nature of the rootstock and scion wood, nature of soil, kind of culture practised in nursery, variety of scion, individuality of seed and scion parent, technique of the propagational method, etc., the difficulties in the way of securing a straight and final answer to each of the various questions on each of the various propagational methods under study will become obvious. Despite all these considerations, it will be found that from a large number of small-scale trials conducted over a number of seasons and from a few large-scale trials have emerged a fund of information of some interest and practical importance. Above all, a stage has now reached when it is possible to visualize and formulate a more definite and fruitful approach to the varied problems confronting the mango propagator than before the commencement of the present investigations.

SUMMARY AND CONCLUSIONS

1. A number of seedling races of mangoes grown on the west coast of the Madras province have been found to be polyembryonic, producing two to five seedlings per seed.

2. Contrary to the popular belief, seeds of some of these polyembryonic varieties are found to produce a fairly high germination. The varieties that are likely to be favoured by nurserymen, because of their high germination capacity and polyembryony, are indicated in the text of the paper.

3. Distortion of seedling stem is found to be a common feature in mango seed-beds when unshelled stones are sown.

4. Sowing of mango stones with plumule up is found to produce in seedlings a straight tap-root and stem, both of which characters facilitate inarching and root-grafting operations.

5. Shelled stones, although they produce a straighter tap-root and stem in seedlings than unshelled stones, and are desirable for elimination of diseased or worm-infested seeds, are not advocated, because of the expensiveness of shelling operation and poor germination of shelled stones.

6. Grading of fruits or stones is not considered as a necessary operation in mango nursery practices, as neither plant vigour nor germination is found to be dependent on size of fruit or stone.

7. Measurable differences in seedling vigour and germinating capacity are noticed between the progenies of different seed parents, and it is therefore inferred that the inherent vigour of the seed parent is a dominating factor masking all possible influences as those of fruit or stone size. Selection of seed parents which produce inherently vigorous progenies are shown to lead to a saving of time and money to the nurserymen by shortening the pre-inarching period.

8. Transplanting of mango seedlings with naked roots is found to be a feasible operation under certain conditions.

9. Heavy defoliation of mango seedlings seven to nine days prior to their lifting from seed-beds has been found to reduce the casualties to the minimum extent.

10. Placing of potted seedlings close together in a trench and letting in of irrigation water thereafter at an interval of three to five days is shown to be a more economical practice than the prevalent system of hand-watering the pots daily in South India.

11. Successful inarching of young seedlings of even 4½ months of age has been found possible.

12. The popular belief that older the rootstock the greater the size of the grafts in the plantation is falsified from the data collected up to 18 months after planting on a Neelum plantation planted to trees on one day

on rootstocks of three different ages, viz. 10½, 13½ and 16½ months at the time of grafting. It is, however, possible that these results may not apply to grafts on very young rootstocks of the type mentioned in the foregoing paragraph.

13. Neelum has contributed to a greater success by inarching than Bangalora.

14. Weather conditions seem to influence to a great extent the success in inarching operation, July-September having proved the optimum and June the worst period for Neelum in 1936.

15. The optimum period from the date of inarching to that of separation from scion parent is found to differ with different varieties, Rumani having shown to demand a longer period than Neelum and Bangalora.

16. It was found possible to plant out grafts in their permanent orchard sites immediately after separation from scion parents during certain seasons. An earlier manifestation of flush was noticed in such grafts than in those which were nursed for a time prior to planting. The appliction of results to all grafts raised under diverse conditions must, however, await results of further investigation.

17. A method of root-grafting in mangoes has been devised successfully, and is described in the text.

18. (*a*) The relative amount of success obtained by root-grafting, double-working, inarching, shield and patch-budding, and cleft-grafting in a comparative trial is presented in the text.

(*b*) On the basis of a number of trials with several methods of budding it is concluded that, budding and side-grafting can both be successfully and advantageously adopted in open beds during certain seasons. Different mango varieties are seen to respond differently to budding operation ; and among the varieties so far tested, Neelum and Erramulgoa have proved to be more suitable for propagation by budding than Bangalora and Alfonso.

(*c*) In side-grafting, the superior value of scions from apical regions of the shoots and of 0·5 cm. or over in diameter has been proved over those from lower parts of the scion shoot and thinner scions respectively. Indication has been afforded that rainy weather does not provide congenial conditions for side-grafting operation. A few plants have been successfully raised by side-grafting with scion wood obtained from a long distance and inserted after three to five days of separation from parent trees.

(*d*) Cleft-grafting and mound-layering after etiolating and ringing of shoots have proved almost a total failure, while double-grafting has been found to be an easy operation producing a very high success in several months.

(*e*) Although success obtained is very low, it is now proved that mango can be raised by hard-wood cutting. Certain growth-promoting substances, which were tried, have not proved efficacious in inducing root-formation in mango cuttings.

19. To study the extent of uniformity in the trees raised by root-grafting, inarching and double-working, and the relation between propagational method and orchard performance, a comprehensive trial has been laid out. In a separate trial under progress, the role of intermediate rootstock in double-worked plants, particularly in increasing tree productivity, is being studied.

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REFERENCES

Burns, W. and Prayag, S. H. (1921). *The book of the mango*: Govt. Central Press, Bombay

Collins, G. N. (1903). *Bull. U. S. Dept. Agric. Bur. Plant Ind.* No. **28**

Fielden, G. St. Clair and Garner, R. J. (1936). *Imp. Bur. Fruit Production Tech. Comm.* No. **7**

Grubb, N. H. (1927). *East Malling Res. Sta. Ann. Rept., 1925*, pp. 11-5

Hatton, R. G. (1932). *Imp. Bur. Fruit Production Teh. Comm.* No. **3**

Higgins, J. E. (1906). *Bull. Hawaii Agric. Expt. Sta.* **42**

Hoblyn, T. N. (1931). *Imp. Bur. Fruit Production Tech. Comm.* No. **2**

Kinman, C. F. (1918). *Bull. Porto Rico Agric. Expt. Sta.* No. **20**

Knight, R. C. (1927). *East Malling Res. Sta. Ann. Rept., 1925*; *Supplement*, pp. 51-63

Leh, van der (1930). *Rept. and Proc. 9th Internat. Hort. Congress (The Royal, Hort. Soc.), 1930*

Paul, W. R. C. and Guneratnam, S. C. (1937). *Trop. Agric.* **88**, 86-91; 331-7

——— (1938). *Trop. Agric.* **90**, 34-5

Popenoe, Wilson (1927). *Manual of tropical and sub-tropical fruits*: The Macmillan & Co. New York, pp. 79-145

Sen, P. K. and Mallik, P. C. (1940). *Proc. 27th Ind. Sci. Cong., Madras, 1940*, Part III: *Abstracts* **43**, 142-3

Swarbrick, Thomas (1930). *J. Pom. and Hort. Sci.* **8**

Swarbrick, Thomas and Roberts, R. H. (1927). *Wisconsin Agric. Expt. Sta. Res. Bull.* **78**

Tanaka, Tyozabura (1939). *Philip. J. Agric.* **10**

Tukey, H. B. (1929). *Bull. New York State Agric. Expt. Sta. Geneva*, No. **569**

Whittaker, E. C. (1940). *Agric. Gaz. N. S. Wales* **51**, 331-6

Woodrow, Marshall (1904). *The mango. Its culture and varieties*: Parsley Alexander Gardner, London, pp. 1-32

Wray, G. W. (1939). *J. Jamaica Agric. Soc.* **43**, 94-5

THE COLD STORAGE OF PEARS (BARTLETT) IN THE PUNJAB

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(With Plate XL and one text-figure)

IN the Punjab, different varieties of pear are grown, e.g. Bartlett, Dutchess of Bordeaux, Easter Beurre, etc., in the hills; *Kashmiri nakh* and *Pathar nakh*, (sand pear) in the plains. In the Kulu valley, the Bartlett is far more popular with the growers than any other variety, and is grown from 4,000 ft. at Kulu, to 6,000 ft. at Manali. This variety is also grown in other parts of India and in fact is largely grown all over the world. In the plains, however, the *Kashmiri nakh*, a recently introduced variety, promises a good future and is even now exported to other provinces.

Pears grown at higher altitudes are much superior in quality to those grown in the plains. Bartlett or Williams pear, a mid-season variety , is excellent for canning and table purposes. It is fairly big in size, very delicious, creamy, sweet in taste, when ripe, with a pleasant aroma. The fruit is very delicate, and when full ripe deteriorates within a few hours.

The Kulu growers, however, have to face certain practical difficulties in the disposal of this fruit, i.e. limited demand for the fruit in the Kulu valley, high transportation charges and the ripening difficulties. Most of this fruit has to be sent out of the valley as there is very little demand for this fruit in Kulu proper. But the grower has to pay very high transportation charges for sending the fruit to the plains, due to transportation monoply and high taxes which, however, are expected to be reduced shortly. The ripening difficulties are also a great handicap in as far as, if the grower sends the fruit in ripe condition, it deteriorates rapidly in the way. But if he sends the fruit in unripe condition to the hot plains of the Punjab, where the temperature varies from 95 to 110° F. at that time the fruit does not ripen and merely shrivels up with the result that the fruit in the glut of the season and in normal years fetches ridiculously low price of eight annas to one rupee per maund in Kulu market. Sometimes it does not even pay to pick the fruit and send the same to the market, with the result that a good deal goes to the manure pit. For this very reason the area under pear is not increasing although there is any scope for expansion of area under this fruit. On the other hand, fruit being of very high quality, is greatly relished by the people in the plains and can fetch good price there.

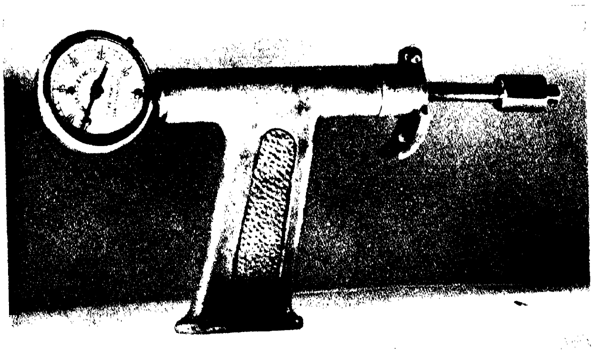
In order to make pear-growing a paying proposition, both in the interest of the grower and the consumer, it was considered necessary to study (*a*) the optimum stage of maturity at which the fruit should be picked and the test for the same, (*b*) handling of the fruit in transit, (*c*) best temperatures for the storage of the fruit of different stages of maturity and effect of disinfecting the fruit and wrapping the same on the storage life of the fruit, (*d*) diseases to be confronted in storage, (*e*) optimum temperature required for the ripening of the fruit after removal from cold storage, (*f*) effect of certain gases in hastening the ripening process of the fruit, and lastly (*g*) the possibilities for cold storage industry. Bartlett pear was thus selected for experimental purposes. These problems were investigated during the past two years, viz. 1938-39, at Lyallpur, under the research scheme 'Cold Storage of Fruits in the Punjab', financed jointly by the Imperial Council of Agricultural Research and the Punjab Government. The relative information available from these experiments and others conducted at the Agricultural Research Institute, Lyallpur, is given in the following few pages. In order to give a more complete information to the reader on the subject, effort has also been made to give necessary information available in literature.

THE TIME OF PICKING AND MATURITY TESTS

Bartlett variety of pear, which was selected for these experiments, is generally ready for picking at the end of July or beginning of August at Kulu, as was determined by the experiments, conducted under the fruit and vegetable preservation scheme, financed jointly by the Punjab Government and the Imperial Council of Agricultural Research. At higher altitudes, however, the ripening is about a week later. The time of picking the fruit in the valley is thus very short and a large bulk of the fruit is harvested within a short space of time.

In America [Magness, 1929], where the pear industry is of very great magnitude, certain criteria, found out by scientific research, are widely adopted for picking the fruit at the appropriate stage of maturity. In this country, however, the fruit is picked by the naked eye judgement, a method which is hardly satisfactory. Experiments conducted here have shown that the fruit should be picked at a stage when it is hard, green, mature and no further changes except ripening processes are to occur, so that it is not easily bruised in transit and ripens properly at the destination.

Various chemical tests, viz. sugar-acid ratios, etc., have been carried out in other countries [Magness, 1929] to find out their relationship with the ripening processes, but no concordant results have so far been found in this direction. In the United States of America [Magness, 1929] there has been found a type of penetrometer commonly known as 'pressure tester' (Plate XL) which measures the resistance of the fruit flesh to a penetrating knob of 5/6 in. in diameter connected to a registering pressure gauge. This knob penetrates the fruit to a depth of 5/6 in. It has been found to be a very useful and handy instrument, the readings of which bear a close relationship to softening of the fruit and its stage of maturity. Trial tests carried out with this type of penetrometer at Kulu (under the fruit and vegetable preservation scheme, Punjab and I. C. A. R.) have shown that for satisfactory transport of fruit to the Punjab plains, Bartlett pear should be picked at a pressure test of about 16-18 lb.



Pressure tester

In addition to the pressure test, the colour of the fruit and the cork formation in the lenticels are good indices that the fruit is ready for picking. A colour chart has also been devised in America [Magness, 1929] which is also very useful. The immature pear has a deep green colour, but when mature it shows a slightly light green colour with only a tinge of yellow in-between the lenticels. The lenticels of immature pear are white and as the fruit matures, cork formation takes place and the lenticels become brown in colour. The development of this brown colour in the lenticels is a very good indication that the fruit will ripen without shrivelling. The development of characteristic smoothness of shiny nature is also a valuable guide to the optimum picking conditions.

It has been found in the United States of America that both the early and late picked pears tend to scald somewhat sooner than pears picked in the mid-season. Fruit of advanced stage of maturity tends to develop breakdown earlier and in fact core-breakdown occurs earlier still, i.e. even when the outer flesh is in good dessert condition, and this emphasizes the importance of picking the fruit at the right stage of maturity.

HANDLING AND TRANSPORT

Experience and research [Magness, 1929; Van der Plank, 1937; Tindale 1938] have shown that it is better to handle the pears under coolest possible condition. Pears should preferably be pre-cooled (fruit cooled to below 40° F. very quickly) for transport and sent in refrigerated vans. But in India such means are still undeveloped and pre-cooling is almost unknown. Still the experiments carried out at Lyallpur on the storage of pears, have shown that pears picked at the right stage of maturity, even if shipped under ordinary conditions of transport, without pre-cooling, can keep long and sent to long distances provided proper ripening and storage facilities exist as will be evident in the succeeding paragraphs.

BEHAVIOUR OF FRUIT IN COLD STORAGE

Fruit of two stages of maturity, viz. A and B, was selected and stored at three different temperatures—32° F., 36° F. and 40° F. Half of the fruit was stored as such and the other half was washed with 5 per cent borax solution for 2-4 minutes. Half of the fruit of the above two lots was wrapped with tissue paper and the other half left unwrapped. Fruit of A-stage of maturity was hard, green, mature, crisp, astringent and acid in taste, pressure about 18 lb. Fruit of B-stage was of advanced maturity than A, and greenish yellow, still crisp, less astringent, slightly less hard but firm, 14 lb. pressure.

The fruits stored at 40° F. (Tables I-IV, Fig. 1) ripened normally within 20 days* in case of B-stage of maturity and 25 days in case of A-stage of maturity and remained thereafter in good condition for a week in storage. Pears rarely scalded so long as they showed even slight green colour. The fruit of A and B stages of maturity, stored at 36° F., behaved in a manner similar to that at 40° F. except that the ripening was slow. It took six and four weeks, respectively, for the fruit of A and B stages of maturity to become yellow ripe at 36° F. The fruit of A and B stages of maturity stored at 32° F. kept in excellent condition for five and four months during the first year, but in the second year, due to some carelessness in handling the fruit in transit, coupled with rather poor condition of the crop and small size of fruit, consequent to the shortage of rainfall, the storage life was reduced to 4½ and 2 months respectively for A and B stages of maturity. The pears in storage gradually turn yellow and, when full yellow, they should not be retained further in storage, otherwise physiological disorders will cause a severe loss of fruit. Borax wash (5 per cent in water) and wrapping had no beneficial effect in prolonging the storage life of the fruit. At the Cold Storage Research Station, Poona, storage life of Bartlett pear from Kashmir has been found to be three months [Karmarkar, 1940].

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*Fruit was considered as properly stored so long as the wastage did not exceed 10 per cent.

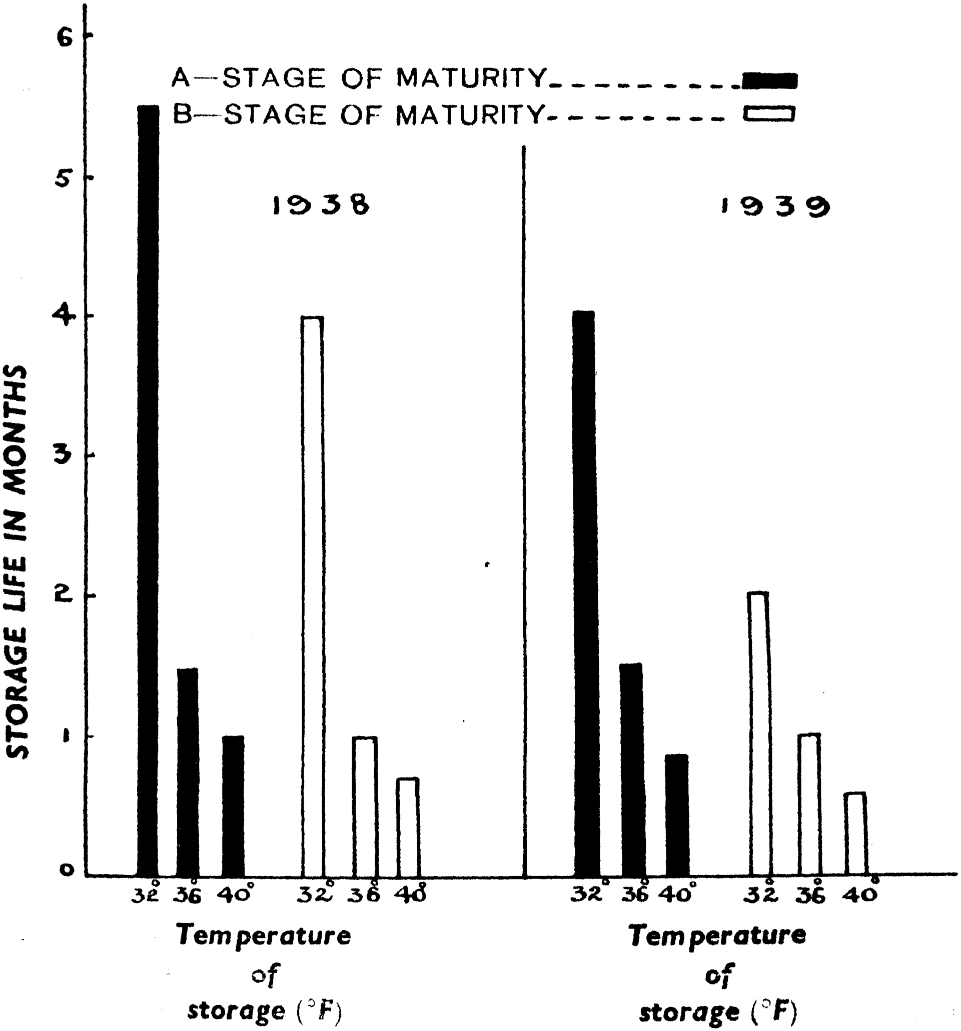

FIG. 1. Storage life of Bartlett pear at different temperatures of storage, 1938-39

TABLE I

Percentage total wastage of fruit (Bartlett pear) of A-stage of maturity, 1938

(60 fruits in each lot : stored on 4 August 1938)

No. of days in storage	Treated with 5 per cent borax						Untreated					
	Wrapped			Unwrapped			Wrapped			Unwrapped		
	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40°F.
15	0	0	5·0	0	0	3·3	0	0	6·6	0	0	0
30	0	0	33·3	0	3·4	33·3	0	5·0	25·0	0	3·3	11·7
45	0	10·0	58·3	0	11·7	50·0	0	21·7	50·0	0	8·3	25·0
60	0	25·0	...	0	23·3	...	0	25·7	...	0	16·6	...
75	1·7	33·3	...	3·3	30·0	...	0	36·6	...	0	27·4	...
90	1·7	...	...	3·3	...	...	0	...	...	0	...	...
105	5·0	...	...	3·3	...	...	0	...	...	0	...	...
115	6·7	...	...	3·3	...	...	0	...	...	0	...	...
131	15·0	...	...	5·0	...	...	0	...	...	0	...	...
150	15·0	...	...	10·0	...	...	3·3	...	...	3·3	...	...
168	21·6	...	...	15·0	...	...	10·3	...	...	10·3	...	...
180	...	...	...	25·0	...	...	23·0	...	...	23·0	...	...

TABLE II

Percentage total wastage of fruit (Bartlett pear) of B-stage of maturity, 1938

(60 fruits in each lot : stored on 4 August 1938)

No of days in storage	Treated with 5 per cent borax						Untreated					
	Wrapped			Unwrapped			Wrapped			Unwrapped		
	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.
15	0	0	0	0	0	0	0	0	0	0	0	0
30	0	1·6	15·0	0	3·3	10·0	0	0	15·0	0	0	6·6
45	0	16·7	41·6	0	13·3	45·0	0	13·3	30·0	0	11·6	23·3
54	0	48·6	...	0	41·6	...	0	38·3	...	0	30·0	...
60	0	...	...	0	...	...	0	...	...	3·0	...	...
75	5·0	...	...	1·7	...	...	0	...	...	3·3	...	...
90	5·0	...	...	1·7	...	...	0	...	...	3·3	...	...
105	13·3	...	...	1·7	...	...	3·3	...	...	6·7	...	...
115	13·3	...	...	6·6	...	...	6·6	...	...	10·0	...	...
131	20·0	...	...	11·6	...	...	16·6	...	...	16·6	...	...

TABLE III

Percentage total wastage of fruit (Bartlett pear) of A-stage of maturity, 1939

(72 fruits in each lot : stored on 14 August 1939)

No of days in storage	Treated with 5 per cent borax						Untreated					
	Wrapped			Unwrapped			Wrapped			Unwrapped		
	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.
20	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	20·8	0	0	16·7	0	0	19·4	0	1·4	9·7
40	0	15·0	60·0	0	9·7	58·3	0	5·6	55·5	0	1·4	50·0
56	4·2	87·5	...	1·4	80·5	...	1·4	79·2	...	0	50·0	...
71	9·7	...	...	1·4	...	...	4·2	...	...	0	...	...
93	12·5	...	...	2·8	...	...	6·9	...	...	1·4	...	...
109	12·5	...	...	4·2	...	...	9·7	...	...	1·4	...	...
124	16·7	...	...	8·5	...	...	12·5	...	...	6·9	...	...
137	50·0	...	..	40·3	...	...	50·0	...	...	36·1	...	...

TABLE IV

Percentage total wastage of fruit (Bartlett pear) of B-stage of maturity, 1939

(72 fruits in each lot : stored on 14 August 1939)

No. of days in storage	Treated with 5 per cent borax						Untreated					
	Wrapped			Unwrapped			Wrapped			Unwrapped		
	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.	32° F.	36° F.	40° F.
17	0	0	0	0	0	0	0	0	0	0	0	0
30	0	5·5	26·4	0	5·5	18·3	0	5·5	20·0	0	5·5	18·0
41	0	44·4	...	0	37·5	...	0	41·7	...	0	36·1	...
48	0	...	...	0	...	...	0	...	...	0	...	...
60	18·0	...	...	15·0	...	...	15·0	...	...	9·7	...	...
75	44·4	...	...	43·1	...	...	32·0	...	...	26·4	...	...

It may be of interest to mention that during the first two years, experiments on pear were confined to only Bartlett variety. In the third year (i.e. 1940-41) trials have been started on two new late varieties, viz. Dutchess of Bordeaux and Easter Beurre, which were placed in cold storage (at 32° F. and 36° F.) on October 10 and 29 respectively. Dutchess of Bordeaux at 32° F. remained in excellent condition until the middle of February and Easter Beurre is in excellent condition even uptil now, i.e. beginning of March. Detailed results on these varieties will be given in a later publication.

In Australia and England [Tindale, 1938; Kidd, 1939] storage in special atmospheres has also been tried. The storage life of pears at 32° F. in an atmosphere of 5 per cent carbon dioxide, was enhanced by 50 per cent. Higher concentrations of this gas caused 'brown heart' trouble in pears. No work, however, has so far been done in India on gas storage of pears.

STORAGE DISEASES

The storage life of the fruit in the cold store is limited by the occurrence of various physiological and pathological diseases. The most common physiological maladies are: (1) scalding, (2) waterlogging, (3) core-breakdown, (4) frost injury or freezing, and (5) over-ripeness. Observations made at Lyallpur during the cold storage trials are briefly described in the following paragraphs :—

Scalding

Scalding or storage scald was observed most when the fruit was stored at 36° and 40° F. The skin in this case became dark brown, while the fruit was still in firm condition. The appearance of scald rendered the fruit unmarketable. If such a fruit was allowed to stand at ripening temperatures (60°-70° F.), it became brown and developed a bad flavour.

Waterlogging

This peculiar trouble was first described by Hartman [1931] in America. A trouble bearing a very close resemblance to the symptoms detailed by Hartman was observed at 32° F. during the cold storage trials at Lyallpur.

The fruit in this case developed a 'glassy, waterlogged' appearance and the breakdown occurred in a definite zone around the core, while the rest of the tissue looked healthy. The glassy appearance in some cases was manifest near the skin but was more common near the core. The fruit, when removed from cold storage to ripening chamber, did not ripen but became brown and pulpy. This disease was more severe in the fruit of advanced stages of maturity

Core-breakdown

The core-breakdown is closely related to waterlogging effect described above. The core area in this case was discoloured and the pulp became mashy. It was manifest at 36° and 40° F.

Frost injury or freezing of pears

Although we have not come across this type of injury in the experiments at Lyallpur, yet in other countries [Hartman, 1937] this trouble has been observed. Pears subjected to low temperature—below 32° F.—either in transit or in storage (due to the presence of 'air pockets' at exceedingly low temperatures) often freeze. The pears when put in the market, become pulpy and are thus ill-suited for marketing. If the core temperature has not gone below 25° F. during freezing, the fruit can be brought back to its normal state if it is subjected to suitable temperatures above freezing point of water. In this connection Hartman [1937] states 'Thawing may be carried out at any temperature between 33° and 65° F. provided the humidity is farily high'. Frozen pears are easily injured and should be handled with great care and thawed by placing them in a single layer or in two.

Over-ripeness

The tissues of the fruit pass through a prime eating condition and gradually soften until the fruit becomes over-ripe, pulpy soft ball, which bursts even if slightly touched.

In addition to the physiological troubles, fungal pathogens were also observed during the storage trials at Lyallpur, but the attacks were never severe. Mostly these fungi were saprophytes (growing on dead and decaying tissues), such as blue and green moulds.

OPTIMUM TEMPERATURE FOR RIPENING

As stated previously the fruit, when picked from trees in ripe condition, cannot be transported without spoilage, but if it is picked in unripe condition and sent to the hot plains, it does not ripen properly, due to high temperatures. The experiments at Lyallpur have shown that fruit ripens best when stored at 60°-70° F. It has also been shown that fruit of A-stage of maturity can be kept for about 4½ months when stored at 32° F., i.e. from August to December or even later. This fruit, after removal from cold storage, has, however, to be conditioned, i.e. allowed to ripen, before it can be put in the market for sale. The best temperature for this has also been found to be 60°-70°F., i.e. just the room temperature in winter season in the plains when the fruit ripens within four to seven days. This is in conformity with the results obtained in other countries [Lutz and Culpepper, 1938]. The ripening rate decreases with lower or higher temperatures than 60°-70° F. The pears should not be allowed to ripen fully for disposal in the market but they should be let out a little bit earlier so that they reach the consumer when they are just ripe.

ARTIFICIAL RIPENING

During ripening, certain esters and ethylene gas are evolved [Hansen and Hartman, 1937 ; Van der Plank, 1937 ; Lutz and Culpeppor, 1938 ; Tindale *et al.*, 1938 ; Kidd and West, 1938 ; Bane, 1938 ; Kaltenbach, 1939 ; Hansen, 1939], the latter is mostly responsible for starting ripening changes in most of the fruits and in certain cases hastens such processes. In other countries ethylene gas is now largely used in hastening the ripening and colouring of many kinds of fruit [Kidd, 1938]. A concentration of one in 5,000-20,000 parts per volume of the gas is considered to be an optimum dose for colouring and ripening purposes, depending upon the kind of fruit, temperature of storage and the extent of leakage of gas in store. In case of pears, ethylene has a very decided effect on the softening of the flesh. But this effect is confined to the period preceding storage. No increase in the rate of ripening can be expected in pears which have been previously held at cold storage temperatures for some time. No experiments in this direction have been carried out at Lyallpur and above are some of the observations recorded in the literature on the subject.

ECONOMIC ASPECTS

The cold storage plant of Lyallpur is of a very small size and is designed only for experimental purposes to find out the best temperature for storage, etc. The running cost of this plant will not give a true picture of the cost of storage on commercial scale. It may be mentioned that in other countries [*Refrigerating data book*, 1934] storage expenses vary from three annas to eight annas per maund, per month. Even if the cost of storage in India may come to Re. 1 per maund, per month, it is clear that even after deducting transportation and other charges, a good margin of profit should accrue, as pears of even most ordinary quality fetch eight annas or more per seer in the market, during December-January and higher still in February-March. With the help of cold storage facilities, pear industry can be developed to a great extent. Pears picked hard, green, mature at a pressure test of 16-18 lb. (during the first week of August), and transported as such, can be conditioned at 60°-70° F. for immediate disposal at the destination, stored at 36° F. for marketing during next month and at 32° F. for the rest of the three months (October, November and December) for further sale.

Pears picked and stored in the above manner can also be profitably used for canning purposes and canning period is greatly increased thereby. Pears ripened under cool conditions develop more pronounced flavour and uniformity of texture than the fruit ripened under ordinary conditions. The canning operation should be completed as soon as possible after the fruit is sufficiently ripe, otherwise loss of fruit occurs from core-breakdown. At the Cannery of the Agricultural College and Research Institute, Lyallpur, the pears are first conditioned in cool storage for getting a product of unifrom stage of maturity and flavour and then canned.

REFERENCES

Bane, R. (1938). *Rept. Fd. Invest. Bd.* (*London*) *1938-39* (*Hort. Abst.* March 1940).

Barker, J. and Furlong, C. R. (1937). *Fd. Invest. Bd.* (*London*) *Lealfet No.* **7**

Hansen, E: (1939). *Plant Physiol.* (*Hort. Abst.* March 1940)

Hansen, E. and Hartman, H. (1937). *Plant Physiol.* **12**, No. 2

Hartman, H. (1931). *Agric. Expt. Sta. Oregon State Agric. College* (*Corvallis*), *Sta. Bull.* **282**

——————(1937). *Ice and Refrigeration*, October 1937.

Kaltenbach, D. (1938). *Int. Rev. Agric.* **29** (March), T-81

Karmarkar, D. V. and Joshi, B. M. (1940). *Indian Farming* **1**, No. 4

Kidd, F. and West, C. (1938). *Rept. Fd. Invest. Bd.* (*London*), *1938-39*

Kidd, F. ; West, C. ; Griffiths, D. G. and Potter, N. A. (1938). *Rept. Fd. Invest. Bd.* (*London*) *1938-39*

Kidd. F. ; West, C. ; Griffiths, D. G. and Potter, N. A. (1940). *Ann. Bot.* **1**, 30

Lutz, J. M. and Culpepper, C. W. (1938) *Tech. Bull. U. S. Dept. Agric.* **590**

Magness, J. R. ; Diehl, H. C. and Allen, F. W. (1929). *Tech. Bull. U. S. Dept. Agric.* **140**

Martin, W. E. (1937). *Bot. Gaz.* **99**, No. 1

Scupin, L. (1938). *Calbe A. S. Mitteilung* No. **36** (Reprint from *Obst. Und Gemus* **2**, February 1938)

Soc. Amer. Refrig. Eng. (1934). *Refrigerating data book*

Tindale, C. B. ; Trout, S. A. and Huelin F. E. (1938). *J. Dept. Agric. Victoria* (*Australia*) (*Bull. Int. Inst. Refrg.* **4** : 1938)

Van der Plank, J. E. (1935). *J. Pom. & Hort. Sci.* **13**, 223

CITRUS MANURING

I. FERTILIZER EXPERIMENT WITH SWEET ORANGE (MALTA) GROWING ON ROUGH LEMON

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THE manurial problem of fruit trees has been studied, perhaps, in lesser detail than any other problem of practical importance pertaining to fruit culture, due primarily to the many difficulties which arise in the conduct of such investigations. Studies of manurial problem by chemical analysis of plant organs and pot experiments have their own limitations and in consequence are not wholly satisfactory. Field experiments are more reliable as these represent natural conditions under which the fruit trees are grown, but owing to the elaborate technique in the lay-out, required of this method, this phase of study has received rather inadequate attention from workers in this field of research. Even if extreme precautions are taken in the preparation of the material and selection of uniform soil, etc. it is not uncommon to find, after the orchard has been established, a considerable variation from tree to tree both in regard to yield and productivity, and such variability has often been attributed to the individuality of trees. Batchelor, Parker and McBride [1928] report that in California an extensive fertilizer trial was started on land the history of which was known for a period of about 40 years before the trees were planted for the purpose of investigation. The land received uniform cultural treatments during this period. In the preparation of the rootstock culling of the under-sized plants was done twice, once at the time of transplanting and again one year after transplanting. A third culling was done at the time when the budded plants were removed to the orchard. Extreme care was exercised in the selection of scion wood also. After the trees were planted, no manurial treatment was given to them for a period of about ten years to find out whether the trees were uniform, but it was found that in spite of all these precautions there was a considerable variation from tree to tree both in regard to growth and productivity.

As far as we are aware, no manurial work of importance on citrus has been done in India so far, but a few workers in other countries have carried out such investigations. Kinman [1915] reports that in Porto Rico a complete fertilizer consisting of nitrogen, phosphoric acid and potash gave the best results. It may, however, be added that the experiment was conducted on a heavy soil devoid of humus and lacking in all the important plant foods. The climate was hot and humid with an annual rainfall of 75 in. well distributed throughout the year. The heavy rainfall favoured the washing away of the top soil. Vaile [1922] reports from California that nitrogen alone proved to be the limiting plant food element and the plots which did not receive nitrogen failed to produce a commercial crop after a few years. Phosphoric acid or potash, singly or together, had no beneficial effect on either the health of the trees or the yield. Again Vaile [1924] collected data from about a thousand citrus growers in California for a period of five years and reports that yield of trees was in proportion to the quantity of nitrogen applied. Booth [1928] mentions that all fertilizers containing nitrogen gave an increased yield in proportion to the amount of nitrogen they contained, and phosphoric acid or potash did not improve the quality of fruit. Chapman [1934] reports that the use of phosphate or phosphorus containing material in nine different field trials on citrus for periods of 5-20 years has in no case resulted in significant increases in fruit, though the phosphate applied definitely penetrated into the root zone. It is reported in C. S. I. R. Aust. [1934-35] that fertilizer experiment conducted at Citricultural Research Station, Griffith, N. S. Wales, showed that mature but not young trees responded to nitrogenous manuring, and citrus trees did not respond to superphosphate. Morris [1936] from Rhodesia, reporting on the effect of different fertilizer treatment on the yield and quality of Valencia Late orange, concludes that nitrogen played the most important part in maintaining tree vigour, high production and good-coloured fruit The size of the fruit remained unaffected. Allwright [1937] from Western Transvaal reports that out of eight combinations of different fertilizers used, sulphate of ammonia and cattle manure gave the greatest yield. Anderssen [1937] conducted an exhaustive manurial experiment on citrus in South Africa and concluded that phosphoric acid, potash and lime did not affect the size of crop and that application of nitrogenous fertilizers caused an increased crop.

These experiments conducted in other countries on the whole go to show that out of the important constituents of plant food, nitrogen proved to be a limiting factor with regard to the productivity in citrus trees. In the Punjab, however, there is no experimental data to show deficiency of one food element or the other in the soils for citrus requirements, but by observational evidence, supported by the experience of fruit growers, one can say almost with certainty, that our soils, specially of canal colonies, lack nitrogen and it is only due to the deficiency of this nutrient element that citrus trees are devitalized and their yield reduced to a considerable extent. Whenever a dose of nitrogenous manure was administered to weak, unproductive citrus trees in several orchards, it invariably resulted in invigorating their growth and increasing their crop. Lander and others [1929] have shown that generally speaking the Punjab soils are not deficient in potash, the average potash contents being 0·72 per cent for the whole province, while a typical sample of soil from Lyallpur contains as much as 0·827 per cent. Most of the Punjab soils have phosphoric acid lying between 0·1 and 0·3 per cent and a representative sample of Lyallpur contained 0·351 per cent P_2O_5, while American soils on the average contain 0·09 per cent of this food constituent.

The above figures show that our soils on the average are richer in potash and phosphoric acid than the American soils. It stands to reason, therefore, that these two nutrient elements cannot perhaps be the limiting factors in our case, especially when those did not have any beneficial effect on the yield of citrus fruits in a country where these are found in less abundance.

Fruit trees derive their nitrogen supply from two main sources, inorganic and organic, and with the ever-increasing area under fruits and intensive vegetable farming, the supply of organic source of nitrogen in the form of farmyard manure, which has hitherto been the only fertilizer used, is becoming very limited day by day. The purpose of these investigations was to find out if the requirements of citrus trees can be met from inorganic commercial concentrated fertilizer and also ascertain the adequate quantity required for each tree.

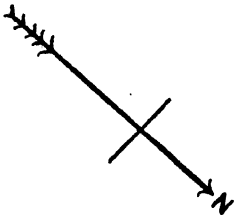
With the facilities provided by the Imperial Chemical Industries, Ltd., India, in giving us free supply of ammonium sulphate and placing at our disposal, by S. S. Sardar Hukam Singh, his garden, an investigation was started in 1933 at Chak 45 G. B. near Gojra, Lyallpur and continued till 1938.

EXPERIMENTAL MATERIAL

A common variety of Malta orange (*Citrus sinensis* Osbeck) growing on seedling rough lemon (*Citrus limonia* Osbeck) rootstock was selected for these investigations from the garden of S. S. Sardar Hukam Singh at Chak 45 G. B. near Gojra, Lyallpur district. This garden comprised an area of about 35 acres under citrus at the time when the experiment was initiated and out of this area an apparently uniform piece of land of about three acres was selected for the investigations and divided into seven sub-plots the details of which are shown in the plan in Fig. 1. Twenty-four uniform trees were earmarked for each of the four treatments, viz. control, 4-lb., 8-lb. and 12-lb. doses of ammonium sulphate. As is clear from the plan a row of trees at the extremity of each sub-plot, a row at either side of the watercourse and a guard row all along the extremity of this area were excluded from the experimental trees.

The lay-out of the experiment is not in strict conformity with the requirements of modern field technique. However, the method of selecting the material was such as to reduce the variation to the minimum. Extreme uniformity of the piece of land of about three acres selected from an area of 35 acres, the rigid selection of only 96 uniform trees out of 501 trees, taking into account not only the growth but also the yielding capacity of each tree before allotting the experimental treatments, eliminating all rows of the trees along the watercourses, keeping a guard row between the plots subjected to different treatments to eliminate the overlapping effect of different doses of the fertilizer and lastly the low coefficients of variability of 8·52-9·28 in the material, will, it is hoped, make up for any defect in the statistical lay-out.

Twenty-four trees varying in girths from 30·4 to 40·7 cm. were selected out of the control plot, and trees practically of the same girths were selected from other sub-plots to be treated with different doses of the fertilizer. Grouping of the trees under different treatments with respect to their girth is shown in Table I, which shows clearly that the material at the outset of the experiment was quite uniform with respect to girth measurements of the trees, which is considered, by common consent, to be the most reliable index of tree growth.



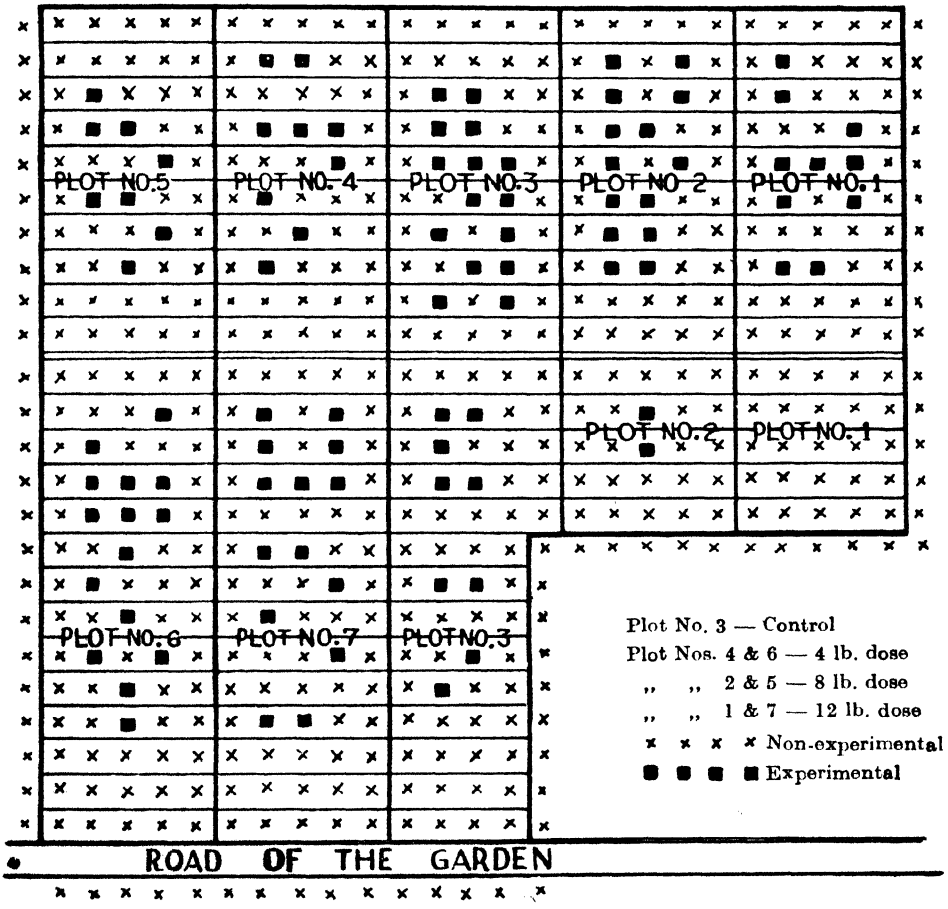


FIG. 1. Plan of the manurial experiment at Chak 45 G. B., Gojra

TABLE I

Grouping of the trees with respect to their girth before these trees were subjected to different treatments

(Girth in cm. in February 1933)

Serial No.	Control	4-lb. dose	8-lb. dose	12-lb. do
1	30·4	30·8	30·0	30·0
2	30·4	31·0	30·3	30·1
3	30·4	31·0	31·0	30·3
4	31·0	31·0	31·4	30·5
5	31·4	32·2	31·5	30·5
6	31·9	32·2	32·0	31·5
7	32·0	32·5	32·0	32·0
8	32·0	32·6	32·5	32·1
9	32·4	33·0	33·0	32·1
10	32·6	33·0	33·3	33·0
11	33·4	33·5	34·0	33·4
12	33·5	34·0	34·5	34·0
13	33·6	34·0	35·0	34·4
14	33·6	34·2	35·2	35·0
15	34·0	35·0	35·5	35·4
16	35·0	36·0	36·6	35·9
17	35·8	36·5	36·9	36·0
18	36·9	36·9	37·0	36·0
19	37·3	37·0	37·0	37·0
20	37·5	38·5	37·6	37·2
21	38·5	38·9	38·2	37·3
22	39·8	40·0	38·6	38·0
23	40·4	40·0	39·4	38·0
24	40·7	41·0	40·4	40·4
Total	824·5	835·8	832·9	820·1
Mean	34·3	34·8	34·7	34·2

The coefficients of variability of trees under the four groups of treatment are shown in Table II. The results show that variability of the material is not particularly high.

TABLE II

Mean girth and coefficients of variability of trees under different treatments

Treatment	Mean of girth in cm.	S. E. of mean	C. V.
Control	34·3	0·65	9·28
4-lb. dose	34·8	0·64	9·04
8-lb. dose	34·7	0·60	8·52
12-lb. dose	34·2	0·58	8·54

Not only should the trees under various treatments be uniform with respect to their growth vigour but their productivity should also be similar. The mean yield records of the trees under different treatments, before the fertilizer was applied, along with standard errors of the means, are shown in Table III. The results bring out clearly that the trees with respect to their yield at the inception of the experiment were quite uniform as the difference between any two of the means is not significant.

TABLE III

Mean yield per tree along with S. E. of mean of the trees under different treatments

Treatment	No. of trees under each treatment	Mean No. of fruit per tree	S. E. of mean
Control	24	209	9·53
4-lb. dose	24	205	10·58
8-lb. dose	24	210	11·91
12-lb. dose	24	211	11·44

The trees were one year 'budlings' when planted in the garden in 1923, and since then till the experiment was started, were receiving uniform cultural treatments and never received any pruning. No manure was applied to these trees for two years before the experiment was started though previously these were receiving farmyard manure as generally practised in the locality. It may, however, be mentioned that at the time of planting, the soil contained a lot of organic matter and the deficiency of this was not evident at the time when the experiment was started. The soil is a deep loamy one, well drained and is typical of the soils met with in the canal colony.

DATA OBTAINED AND METHODS EMPLOYED

Application of the fertilizer

Three doses of ammonium sulphate, viz. 4 lb., 8 lb. and 12 lb., were applied annually per tree from 1934 to 1938 to plots under the respective treatments. The fertilizer was applied twice annually by splitting the dose into two equal halves, as Lyon and others [1923] have shown that heavy applications of available nitrates in early spring disappear from the soil by mid season, and Potter [1927] and Murneik [1928] have shown that a renewed supply of nitrogen in mid-summer increased the size of the fruit. The first application was given each year prior to blossoming, i e. in the third week of February, and the second application in the middle of May. Due to the appearance of mottle leaf on control and fertilized trees in 1937, it was considered advisable to give a supplementary basal dressing of 60 lb. farmyard manure per tree to all the trees under the experiment, including the control, and this was done in February 1937 along with the first dressing of the fertilizer during that year. The method of applying the fertilizer was to weigh the dose separately to be applied to each tree, mix an equal amount of canal silt with it and broadcast the mixture around the tree extending about two feet beyond the spread of the branches. In a radius of 1½ ft. all around the trunk, no fertilizer was applied. The fertilizer was applied to trees under all the treatments on the same day and, after it was broadcast, was mixed in the soil with spades, and irrigation water applied immediately in basins round each tree. The basins, after these were filled with irrigation water, were closed to prevent the water from escaping. As far as practicable, an equal amount of irrigation water was applied to the trees under various treatments. It may be mentioned that the fertilizer was applied to all the trees in the sub-plots earmarked for various doses but the results have been statistically examined only in the case of those trees which were grouped at the outset of the experiment.

Girth measurements

At a height of 6 in. from the ground, trunks of the trees were marked with a circular ring of coal tar, and every year, during the month of February, girth measurements were taken at these points with a steel tape up to 1/10 cm.

Yield records

The number of fruits formed the criterion for judging the yield under various treatments. Weight, grade and quality of fruit under various treatments did not exhibit any appreciable difference and consequently were not studied in detail. The fruits were counted while on the trees during the months of September or October every year. The method of counting the fruits was to take main limbs of the tree one by one and go on marking the fruit on each limb with red clay by means of a long stick, one end of which was wrapped with cotton and dipped, when required, into a thick solution made out of the clay. Each fruit when it was marked was counted by the marker. The clay left a prominent red mark on each fruit which avoided recounting the fruits, already counted, and also ensured by rechecking that no fruit was left over uncounted.

Statistical methods employed

Each year's data with regard to both yield and girth measurements were analysed by the method of analysis of variance recommended by Fisher [1932].

	D.F.	
Between treatments	3	
Within treatments (error) . .	92	
Total .	95	(24 trees per treatment and 4 treatments)

The method of covariance was applied making use of the pre-experimental year's (1933) data to correct the experimental year's data. Differences were compared at 5 per cent level of significance.

PRESENTATION OF DATA

1. *Girth measurements*

The mean yearly girth measurements from 1934 to 1938 of the trees under different treatments are given in Table IV.

TABLE IV

Adjusted mean girths in cm. with their standard errors

Treatment	1934		1935		1936		1937		1938	
	Mean	S. E.	Mean	S. E.	Mean	S. E.	Mean	S. E.	Mean	S. E.
Control . .	36·9	0·222	38·8	0·321	39·8	0·625	41·2	0·507	41·9	0·622
4-lb. dose .	37·2	0·222	38·6	0·321	40·5	0·625	42·1	0·507	43·7	0·622
8-lb. dose .	37·5	0·222	38·8	0·321	40·2	0·625	41·6	0·507	43·3	0·622
12-lb. dose .	37·5	0·222	38·6	0·321	39·8	0·625	41·6	0·507	42·6	0·622

From Table IV critical differences for significance between the mean girths of trees under various treatments have been calculated and shown in Table V.*

TABLE V

Observed differences between the adjusted mean girths of various treatments and the critical differences for significance ($P = 0 \cdot 05$)

Treatment	1934		1935		1936		1937		1938	
	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.
Control and 4 lb. dose	0·3	0·63	0·2	0·91	0·7	1·77	0·9	1·44	1·8	1·77
Control and 8 lb. dose	0·6	0·63	0·0	0·91	0·4	1·77	0·4	1·44	1·4	1·77
Control and 12 lb. dose	0·6	0·63	0·2	0·91	0·0	1·77	0·4	1·44	0·7	1·77
4 lb. dose and 8 lb. dose	0·3	0·63	0·2	0·91	0·3	1·77	0·5	1·44	0·4	1·77
4 lb. dose and 12 lb. dose	0·3	0·63	0·0	0·91	0·7	1·77	0·5	1·44	1·1	1·77
8 lb. dose and 12 lb. dose	0·0	0·63	0·2	0·91	0·4	1·77	0·0	1·44	0·7	1·77

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* In this calculation (and also in Table VII) no allowance has been made for the fact that the corrected means are no longer independent. But the application of the exact formula [Wishart] does not affect the critical difference appreciably

If comparison is made between differences of the mean girth of various treatments, it is evident that in 1934 all the three doses of the fertilizer have not significantly affected the size of the trees as manifested by girth records. The mean girths of various doses when compared among themselves have not also differed significantly from each other. In 1935, 1936 and 1937, the observed differences are all less than the critical difference for significance, and hence the treatments have not affected the girths of the trees. In 1938 the mean girth of 4-lb. treated trees is higher than the mean girth of untreated trees, there being no difference between the mean girths of control and 8-lb. treated trees, and control and 12-lb. treated trees. It may be recalled here that in 1938 organic matter was actually applied to the trees in the form of farmyard manure in the preceding spring.

2. *Yield records*

The mean number of fruits per tree under various treatments is given in Table VI.

TABLE VI

Adjusted mean yields in number of fruits per tree with their standard errors

Treatment	1934		1935		1936		1937		1938	
	Mean	S. E.	Mean	S. E.	Mean	S. E.	Mean	S. E.	Mean	S. E.
Control . .	264·8	15·09	293·8	17·72	236·4	13·12	80·0	9·77	67·9	12·41
4-b. dose . .	332·5	15·09	309·7	17·72	265·7	13·12	113·3	9·77	200·0	12·41
8-lb. dose . .	318·1	15·09	326·0	17·72	268·7	13·12	116·9	9·77	198·6	12·41
21-lbs. dose .	311·4	15·09	348·3	17·72	276·5	13·12	144·8	9·77	199·4	12·41

From Table VI critical differences for significance between the mean yields of trees under various treatments have been calculated and shown in Table VII.

TABLE VII

Observed differences between the adjusted mean yields of various treatments and the critical differences for significance (P=*0·05*)

Treatment	1934		1935		1936		1937		1938	
	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.	Act. diff.	Crit. diff.
Control and 4 lb. dose	67·7	42·91	15·9	50·39	29·3	37·28	33·3	27·79	132·1	35·29
Control and 8 lb. dose	53·3	42·91	32·2	50·39	32·3	37·28	36·9	27·79	130·7	35·29
Control and 12 lb. dose	46·6	42·91	54·5	50·39	40·1	37·28	64·8	27·79	131·5	35·29
4 lb. and 8 lb. dose	14·4	42·91	16·3	50·39	3·0	37·28	3·6	27·79	1·4	35·29
4 lb. and 12 lb. dose	21·1	42·91	38·6	50·39	10·8	37·28	31·5	27·79	0·6	35·20
8 lb. and 12 lb. dose	6·7	42·91	22·3	50·39	7·8	37·28	27·9	27·79	0·8	35·29

Table VII shows that in 1934 all the three treatments, i.e. 4 lb., 8 lb. and 12 lb. doses, gave significantly higher yield than control, whereas there was no significant difference between the mean yields of various doses. In 1935 the differences between the yields of control and 4 lb. dose, and control and 8 lb. dose were not significantly different, while 12 lb. dose gave an increased yield over the control. The difference between the means of various doses was not significant during this year. In 1936 also the behaviour of trees under various treatments with respect to yield was the same as in the previous year, i.e. 12 lb. dose gave an increased yield over the control, there being no significant difference between control and 4 lb. dose, and control and 8 lb. dose. Also the differences between the various doses were not significantly different from one another. In 1937 all the manured trees gave higher yield than the control. Also 12 lb. dose gave higher yield than 4 lb. dose, there being no definitely significant difference between 8 lb. and 12 lb. doses. In 1938 all doses of the fertilizer gave an increased yield over control, there being no significant difference between the various doses.

3. *Relative effect of the fertilizer on the yield*

The percentage increases in yield of manured trees over the control from 1934 to 1938 are presented in Table VIII.

TABLE VIII

Percentage increase in yield of manured trees over the control

Treatment	Percentage increase in yield				
	1934	1935	1936	1937	1938
4 lb. dose . .	24·5	4·4	10·8	41·2	192·6
8 lb. dose . .	20·3	11·2	13·0	46·2	192·6
12 lb. dose .	18·1	19·0	16·8	81·2	194·1

During 1934, treated trees gave an increase over the control to the extent of 18·1-24·5 per cent. In 1935, though there was an increased yield over the control, it was not of the same magnitude as in the previous year, especially in 4 lb. and 8 lb. doses, though 12 lb. dose maintained the percentage increase to the same level as in 1934. In 1936, a slight increase in yield occurred in 4 lb. dose as compared to 1935, but it did not reach the level of 1934. In 1937, the manured trees gave an increased yield over the control from 41·2 to 81·2 per cent, the increases being in the same order as the doses. It is clear that during this year the increases in yield over the control were higher than in all the previous years. During the last year of the experiment, i.e. 1938, the percentage increases in yield of manured trees over the control were the highest recorded. An increase to the extent of 192·6-194·1 per cent was observed over the control during this year. It may be recalled that during the preceding year, i.e. 1937, 60 lb. of farmyard manure per tree were added in addition to the usual doses of the fertilizer.

4. *Yield records of all the trees in various blocks*

The data presented under sub-section 2 and statistically examined relates to 24 trees each under different treatments. But it may be pointed out that yield records were kept for all the trees in various plots numbering 111 under control, 120 under 4 lb. dose, 125 under 8 lb. dose and 145 under 12 lb. dose. Since these trees were not uniform in size these were classified according to their size in different groups, viz. A, B, C and D, A being the biggest and D the smallest so that the trees of different sizes, in each treatment could be compared with trees of corresponding size in the other treatments.

Due to considerable variations in size and yield of individual trees even in the same group under different treatments, it was not possible to include all the trees in the experiment for the purpose of statistical interpretation of the results. The appendix gives mean yield of all the trees in each group under each treatment, which bears out in a general way the results obtained in the case of 24 uniform trees selected for statistical analysis of the results. Mean yields of all the trees under various treatments for a period of five years are given in Table IX, which shows that manured trees have invariably given higher yield than control, and further that 4 lb. dose per tree has also proved to be the best.

TABLE IX

Mean yields of all trees for a period of five years

Grade	Control	4 lb. dose	8 lb. dose	12 lb. dose
A	339	457	415	428
B	222	350	270	275
C	176	230	196	203
D	114	147	144	157

5. *Relation of growth to productivity*

From Table II (which contains mean girths of trees in 1933) and Table IV (which contains mean girths of trees from 1934 to 1938), percentage increase or decrease of girth over the control is recalculated and presented in Table XI. The method of calculation was to subtract the mean value of girth for a year from the mean girth of the following year for all the treatments. The differences thus obtained and given in Table X show the increase in girth of trees from year to year. From these differences (Table X), percentage increase or decrease in girth of the manured trees over the control were calculated.

TABLE X

Actual increase in the mean girths of trees over the preceding year from 1934 to 1938

Treatment	Increase in mean girths from				
	1933 to 1934	1934 to 1935	1935 to 1936	1936 to 1937	1937 to 1938
Control . .	2·4	1·9	1·1	1·2	0·8
4 lb. dose . .	2·8	1·4	1·8	1·8	1·5
8 lb. dose . .	3·0	1·3	1·4	1·6	1·5
12 lb. dose .	3·1	1·1	1·3	1·6	1·1

TABLE XI

Percentage increase or decrease in girths of manured trees over the control

Treatment	Percentage increase or decrease in girth				
	1934	1935	1936	1937	1938
4 lb. dose . .	+16·6	—26·3	+63·6	+50·0	+87·5
8 lb. dose . .	+25·0	—31·6	+27·2	+33·3	+87·5
12 lb. dose .	+29·1	—42·1	+18·2	+33·3	+37·5

If Table XI (girths) is compared with Table VIII (yields), it is quite clear that in 1934 the percentage increase in girth over the control was in order of the quantity of the fertilizer applied, i.e. 12 lb. dose gave the highest increase in girth and 4 lb. dose the least with 8 lb. dose falling between the two. Now looking at Table VIII it is evident that the position is reversed in case of percentage increase in yield, 4 lb. giving the highest increase and 12 lb. the least. During 1935 percentage decrease in girth occurred over the control, the amount of decrease being greater in higher doses. The yields, on the other hand, were higher in higher doses, showing an inverse relationship between growth and productivity during the same year. In the subsequent years also the same relation in general existed between growth and productivity, i.e. when the percentage increase in crop over the control was higher, the percentage increase in the girth was lower and *vice versa*, thus showing that fruiting and vegetative growth are always at the expense of each other, or that fruiting is a dwarfing process.

6. Relative economy of various doses

The mean yield per tree per season for the period under the experiment worked out to be 189, 243, 246 and, 257 fruits, respectively for control 4 lb., 8 lb. and 12 lb. doses, which shows an annual increase of 54, 57 and 68 fruits per tree of various doses over the control. Taking 109 trees per acre (the trees in the orchard are planted 20 ft. apart on square system) the increase in yield per acre over the control comes to 5886, 6213 and 7412 fruits respectively for trees treated with 4 lb., 8 lb., 12 lb. doses. The extra price realized per acre by the use of the fertilizer works out to be as follows. The actual prices of Malta oranges prevalent in the market as well as the price of the fertilizer during different years form the basis of calculation.

Price of Malta oranges	4 lb. dose	8 lb. dose	12 lb. dose
	Rs. A. P.	Rs. A. P.	Rs. A. P.
Price of Malta oranges produced in excess over control	114 0 7	120 6 0	143 9 8
Cost of the fertilizer	24 15 0	49 14 0	74 13 0
Net income	89 1 7	70 8 0	68 12 8

It is clear from the above that the most profitable dose is the least dose, i.e. 4 lb.

DISCUSSION

Local variety of sweet orange growing on rough lemon rootstock constituted the material used for these investigations. The stock portion of the plants being of seedling origin, no doubt, introduces an element of uncertainty with regard to the genetic constitution of the rootstock, but investigations in this line of research have not proved conclusively the advantages or disadvantages of clone and seedling roots over one another in producing uniform plants budded or grafted on them. Hatton [1931] reports that the trees on seedling rootstocks were more variable than those on clones with respect to girth and yield, while Roberts [1927, 1929] associates such variability with causes other than the constitution of rootstocks. That grading of rootstocks, whether clone or seedling, would ensure more uniform trees is accepted almost by every horticulturist. A rootstock may be raised by vegetative means and unless it is uniformly graded it would give rise to material more variable than seedling stocks properly graded. Anthony and Yerks [1928], comparing the growth made by trees on seedling rootstock with those on clone rootstock, state that more uniform sizing of the trees on commercial seedling roots continued to maintain higher degree of uniformity in the orhard. In the material under study though no grading of the rootstock was done prior to the insertion of buds or at the time when the trees were planted in the orchard, yet the method of grouping of trees at the outset of the experiment, where it was shown that the trees with respect to growth and productivity were quite uniform and were growing on a uniform piece of land, coupled with the ability of rough lemon rootstock to produce 90-100 per cent apogamic seedlings [Marloth, 1938] amply justifies the suitability of the material for the investigation carried out and reported in this paper. Variant seedlings which were found by Webber [1932] to produce almost weak and dwarfed orchard trees, would undoubtedly be eliminated as a result of the method employed in the selection of the material.

In 1938, due to the presence of organic matter in the soil in the form of farmyard manure, 4-lb. treated trees gave increased girths over the control. But growth records of trees from 1934 to 1937, as manifested in their girth measurements, show that size of the trees under various treatments was not apparently affected—control and manured trees not showing any significant difference in their size. Increased yield obtained in the case of manured trees, therefore, cannot be attributed to bigger trees producing more potential bearing surface. While the bearing surface of the trees under various treatments remained the same, fruiting in the manured trees was increased, showing that nitrogen was a limiting factor in the setting and subsequent development of fruits in control trees. The importance of an adequate amount of nitrogen at the time of setting of fruit and its subsequent development has been emphasized by many. Hooker [1920], Harley [1925] and Schrader and Auchter [1925] report that fruiting spurs had a greater percentage of total nitrogen than non-fruiting spurs about the end of June. Determination of the nitrogen content of fruit of Eureka lemon, Washington Navel orange and Marsh grapefruit were made by Cameron and others [1936] at fortnightly intervals at Riverside California and also in the case of two oranges at Los Angeles. They have shown that the total nitrogen increased at approximately the same rate throughout the period of fruit development. Anderssen [1937] reports that application of nitrogenous fertilizer caused an increased crop, the increase in tree size did not exceed that of the control, but was rather the reverse.

The manured trees responded more in the way of giving higher yield in later years, especially in 1938. This in part may be due to steady depletion of nitrogen from the control plot year after year. But the highest percentage yield obtained during 1938 suggests that probably it was the lack of organic matter in the soil that was responsible for the fertilized trees not making use of inorganic supply of nitrogen to such an extent as they did when organic matter was applied in the form of farmyard manure. Even though adequate quantities of plant nutrients are present in a soil, these may not become available to the plants, due to lack of organic matter, in the absence of which soil organisms, making the nitrogenous plant food available from unavailable form, are altogether inadequate or inactive. Even unavailable forms of potash and phosphoric acid are not generally made available in the absence of organic matter. The lack of organic matter in control and treated plots was evident in 1937 when the trees began to develop mottle leaf. Vaile [1922, 1924] mentions that the use of nitrogen in the form of concentrated commercial fertilizer led to the development of mottle leaf and the trees became practically unproductive after a few years and bulky organic manure caused less mottling as compared to the concentrated nitrogenous manure. Chapman [1938] recommends the use of bulky organic material in citrus orchards in California. In view of the results obtained from this experiment and the findings of others, it is suggested that along with inorganic nitrogenous concentrated fertilizers, an adequate amount of organic matter be added to the trees to obtain best results.

It has been shown that 8 or 12 lb. dose of the fertilizer did not give significantly increased yields over 4 lb. dose excepting in one season when 12 lb. dose gave significantly higher yield than 4 lb. dose. The most profitable dose under the conditions of the experiment was of 4 lb. and any increase of the fertilizer over this dose seems to be unnecessary as it did not affect either the size of crop or vigour of the trees. The same results were obtained by Anderssen [1937] who concludes that the application of ammonium sulphate to soil induced very marked increase in weight of crop and number of fruits and there was no significant difference in crop, however, between applications of 2, 4 and 6 lb. of ammonium sulphate per tree. It is proposed to lay out an experiment to determine the efficacy of still smaller dose of ammonium sulphate.

SUMMARY AND CONCLUSIONS

1. The paper deals with the investigations carried out at Chak 45 G. B., Gojra, Lyallpur, from 1933 to 1938 on citrus manuring.

2. Yield records were kept for all the trees of common variety of Malta, which were nine years old, in various plots under different treatments numbering 111 under control, 120 under 4 lb. dose, 125 under 8 lb. dose and 145 under 12 lb. dose. Out of these, 24 trees were selected in 1932 under each of the four treatments and were grouped for their uniformity with regard to growth and productivity before any fertilizer was applied.

3. Three doses of ammonium sulphate, viz. 4 lb.,8 lb., and 12 lb., were applied annually per tree from 1933 to 1937 to the plots under the respective treatment. The fertilizer was applied half prior to blossoming, i.e. third week of February, and the remaining half in the middle of May. A fourth lot of trees was kept as control. In February 1937, a supplementary basal dressing of 60 lb. farmyard manure was applied per tree to all the four treatments including the control because of the appearance of mottle leaf.

4. Girth measurements and yield records were taken each year from the inception to the conclusion of the experiment.

5. The data with respect to growth and productivity of 24 grouped trees were examined statistically.

6. In the absence of an adequate amount of organic matter in the soil application of various doses of the fertilizer did not affect the size of trees. Control and treated trees did not exhibit any significant difference in their size.

7. In the presence of farmyard manure in the soil, 4-lb. treated trees grew bigger in size than the untreated ones.

8. Manured trees gave increased yield over control.

9. There was no significant difference in the number of fruits produced on trees receiving different doses of the fertilizer, i.e. 4, 8 and 12 lb. per tree.

10. The lack of organic matter in the soil caused mottle leaf.

11. Fertilizer in conjunction with farmyard manure gave increased yield over the fertilizer alone.

12. Fruiting dwarfed the trees in proportion to the amount of crop borne.

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REFERENCES

Allwright, W. J. (1937). *Western Transvaal Publication (mimeographed) S. Afr. Coop Citrus Exchange*

Anderssen, F. G. (1937). *J. Pom. & Hort. Sci.* **15,** 117-59

Anthony, R. D. and Yerks, G. E. (1928). *Proc. Amer. Soc. Hort. Sci.* **69**

Batchelor, L. D.; Parker, E. R. and McBride Robert (1928). *Calif. Agric. Expt. Sta. Bull.* **451**

Booth, C. T. (1928). *Cheffy Fertilizer Expt. Ann. Rept.* **12,** 7

C. S. I. R. Aust. (1934-35). *Griffith Citri Res. Sta. Ann. Rept.*, p. 8

Cameron, S. H. and others (1935-36). *Proc. Amer. Soc. Hort. Sci.* **33,** 87-9

Chapman, H. D. (1934). *Calif. Agric. Exp. Sta. Bull.* **571**

——————— (1938). *Calif. Citrogr.* **23**

Fisher, R. A. (1932). *Statistical methods for research workers* (Fourth edn.) : Oliver and Boyd, Edinburgh

Harley, C. P. (1925). *Proc. Amer. Soc. Hort. Sci.* **22**

Hatton, R. G. (1928-30). *Ann. Rept. East Mall. Res. Sta. II Supplement*, pp. 13-21

Hooker, H. D., Jr. (1920). *Mo. Agric. Expt. Sta. Res. Bull.* **40**

Kinman, C. F. (1915). *P. R. Dept. Agric. Bull.* **18**

Lander, P. E., Ramji Narain and Mehta, M. L. (1929). *Mem. Dept. Agric. India (Chem. Ser.)* **10,** No. 2

Lyon, T. L. and Heinicke, A. J. (1923). *Cornell Agric. Expt. Sta. Memoirs* **63**

Morloth, R. H. (1938). *Dept. Agric. and Forestry, Union South Africa, Reprint No.* **50**

Morris, A. A. (1936). *Ann. Rept. Mazoe Citrus Exp. Sta., 1936*

Murneek, A.E. (1928). *Mo. Agric. Expt. Sta. Res. Bull.* **119**

Potter G. F. (1927). *Proc. Amer. Soc. Hort. Sci.* **24,** 234-6

Roberts, R. H. (1927). *Wis. Agric. Expt. Sta. Res. Bull.* **77**

——————— (1929). *Wis. Agric. Expt. Sta. Res. Bull.* **94**

Schrader, A. L. and Auchter, E. C. (1925). *Proc. Amer. Soc. Hort. Sci.* 150-60

Vaile, R. S. (1922). *Univ. Calif. Agric. Exp. Sta. Bull.* **345**

——————— (1924). *Calif. Agric. Expt. Sta. Bull.* **374**

Webber, H. J. (1932). *Hilgardia* **7,** 1-79

APPENDIX

Mean yield (number of fruits) per tree of all the grades of trees under different treatments 1934-38*

Grades of trees	A				B				C				D			
Treatments	Control	4 lb, dose	8 lb. dose	12 lb. dose	Control	4 lb. dose	8 lb. dose	12 lb. dose	Control	4 lb. dose	8 lb. dose	12 lb. dose	Control	4 lb. dose	8 lb. dose	12 lb. dose
1934 . .	376	548	562	587	276	413	371	364	224	316	279	242	127	170	156	163
1935 . .	512	629	600	520	335	481	371	373	280	289	254	303	170	195	252	249
1936 . .	409	462	420	435	281	393	290	287	215	237	216	205	137	157	141	139
1937 . .	203	248	192	211	108	165	98	142	85	111	82	93	64	77	67	87
1938 . .	194	397	303	386	112	299	221	212	75	198	152	175	72	137	104	146
Total .	1,694	2,284	2,077	2,139	1,112	1,751	1,351	1,378	879	1,151	983	1,018	570	736	720	784
Mean .	339	457	415	428	222	350	270	275	176	230	196	203	114	147	144	157

*Total number of trees under experiment being 501, i.e. 111 under control, 120 under 4 lb. dose, 125 under 8 lb. dose and 145 under 12 lb. dose

A KEY FOR THE IDENTIFICATION OF THE LARVAE OF THE KNOWN LEPIDOPTEROUS BORERS OF SUGARCANE IN INDIA BASED ON MORPHOLOGICAL CHARACTERS

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(With Plates XLI—XLV)

THE following is an account of the study of the external morphology of the larvæ of the common caterpillar borers in sugarcane in India carried out with a view to preparing a key for their identification in the larval stage.

A classification of the borers of sugarcane, rice, etc. was published by Fletcher and Ghosh [1919], Ghosh [1921] and Fletcher [1927] based on body colour and stripes and differentiating morphological characters. The first-named two publications give details of life-history, seasonal history and alternative host plants. A recent paper by Gupta [1940] has dealt with the anatomy, life and seasonal history of four species of striped moth borers in northern Bihar and western United Provinces. The setal arrangement and the external morphological characters of the larvæ are described and utilized for their differentiation.

This paper deals with an alternative classification of the common caterpillar borers of only sugarcane based mainly on a study of the setal characters, some other morphological characters being also taken into consideration for purposes of differentiation.

The study of Lepidopterous larvæ in general made by Dyar [1893-95 ; 1910], Forbes [1910], Fracker [1915], etc. in America has led to the conclusion that certain of the setae (primary and sub-primary) borne by the caterpillars on their body segments are always constant and their variation in position and number afford valuable characters for classification. Classifications of the Lepidopterous larvæ in general based on the setal arrangement have been published by the above-named authors.

For a proper understanding of the positions normally occupied by the setae, it is necessary to examine a typical segment. A segment may contain three kinds of setæ, namely, (1) primary, which are found in the first instar and are constant throughout the larval life, (2) sub-primary, which appear after the first moult of the larva and are fairly constant throughout all the succeeding instars and (3) secondary, which appear in later instars, are not constant, do not assume definite positions and bear no relation to the primary setæ.

The maximum number of primary and sub-primary setæ that can appear in any of the segments, according to Fracker [1915], is about 15. All these setæ are rarely borne by any one species, as variations and reductions are common. A hypothetical segment bearing all these setæ in their normal positions named after Greek letters by Fracker would be as shown in Plate XLI, fig. 1 (the area covered by the rectangle represents the area between the mid-dorsal and mid-ventral line of a segment on one side and the positions of all setæ correspond to their natural positions on the segment) :—

There are six setæ above the spiracle, in two vertical rows of three setæ each, the cephalic row consisting of alpha, gamma, and epsilon, the caudal row consisting of beta, delta and rho. At the level of the spiracle is theta. Just below the spiracle, are two setæ, kappa and eta. At the outer base on the leg, two setæ pi and nu, and the inner base of the leg near the mid-ventral line, sigma, tau and omega. Between kappa and pi towards the caudal border of the segment, one seta, mu. Among these, except theta and mu which are sub-primary, all setæ are primary.

Some of the setæ mentioned above are always found in association with one another and hence are designated as a group bearing the name of one of the setæ of the group as for instance, ' kappa ' group represents kappa and eta, ' pi ' group represents pi and nu.

The system adopted by Dyar and followed by Forbes and others consists in giving Roman numerals to the setae starting from the mid-dorsal line downwards. According to Dyar [1893-95] there are two types of arrangement :— ' The first, which is by far the most generalized, consists (considering only the abdominal segments) of five tubercles above the spiracle on each side, three in a transverse row about the middle of the segment and two behind ; below the spiracle are two oblique rows containing, respectively, two and four tubercles. This type is found in Hepialus and is probably typical of the moths in Prof. Comstock's first sub-order, the Jugatæ.

The second type contains two dissimilar lines of modifications of the first type ; but as they agree in number of the tubercles and in other characters they are considered together. The fundamental arrangement of the tubercles is as follows :—on each side above the spiracle three tubercles ; below or behind the spiracle and above the base of the leg, three more ; on the base of the leg three (or four) on the outside and one on the inside near the mid-ventral line. These are designated thus counting from the dorsal line :— Tubercles I, II, III, above the spiracle ; IV, V, VI, below ; the group of three on the outside of the leg as VII and the single one on the inside of the leg as VIII. Tubercles VII and VIII are present also on the legless abdominal segmengs in the corresponding position '.

In this nomenclature certain minute setæ which are very inconspicuous, save in a few cases, have not been included. Forbes [1921] calls these the small primaries and has designated them thus :—

IIIa—a small seta found near Tubercle III.

Xa, Xb, Xc, Xd—variable number of small setæ found between tubercles I and III.

IXa, IXb—variable number of small setæ found cephalad of the base of leg (Fracker, however has included all these setæ in his nomenclature and the corresponding names are as follows) :—

IIIa—epsilon,
Xa, Xb, Xc, Xd—gamma,
IXa, IXb—omega, phi.

A typical segment (abdominal) bearing all the setae enumerated above will therefore be as shown in Plate XLI, fig. 2.

The homology between Fracker's nomenclature and that of Dyar will therefore be as follows :—

Fracker	Forbes (after Dyar)—(abdomen)*	
	Frenatæ	Jugatæ
alpha	I	I
beta	II	II
gamma	X	X
delta	Absent	Absent
epsilon	IIIa	IIIa
rho	III	III
theta	Absent	IV
kappa	IV	V
eta	V	VI
mu	VI	Absent
pi	VIIa	VIIa
nu	VIIb	VIIb
sigma	VIII	VIII
omega	IXa	IXa
phi	IXb	IXb

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* Here the comparison is shown only between abdominal setæ because in this paper only the abdominal setae have been utilized for the purposes of differentiation.

The borers the differentiation of which is set out in this paper are the common pests of sugarcane in India. They are 12 species belonging to three families and five sub-families, as follows :—

Name of species	Habit	Family	Sub-family
1. *Scirpophaga nivella* F.	Top shoot borer	Pyralidæ	Schoenobiinæ
2. *Argyria sticticraspis* Hmpsn.	Stem borers	Pyralidae	Crambinæ
3. *Argyria tumidicostalis* Hmpsn.			
4. *Diatraea auricilia* Dudgn.			
5. *Diatraea venosata* Wlk.			
6. *Chilo zonellus* Swinh.			
7. *Chilo trypetes* Bisset			
8. *Raphimetopus ablutella* Zell.	Stem borer	Pyralidae	Anerastinæ
9. *Emmalocera depressella* Swinh.	Root borer	Pyralidae	Anerastinæ
10. *Sesamia inferens* Wlk.	Stem borer	Noctuidæ	Acronyctinæ
11. *Sesamia uniformis* Dudgn.	Stem borer	Noctuidæ	Acronyctinæ
12. *Procometis trochala* Meyr.	Stem borer	Cryptophasidæ	

Method of study and characters employed

Full-grown or nearly full-grown larvæ of the 12 species mentioned above were used for the study. At least 12 specimens of each species were examined. Permanent mounts of the head capsule and entire skin were made in Canada balsam on slides for examination under microscope.

For the study of the chætotaxy of the body segments diagrammatic sketches were drawn in the standard way followed by Fracker, Forbes, etc., i.e. the area covered between the mid-dorsal line and mid-ventral line in a segment on one side being represented as a rectangle and the setae within this area plotted in their corresponding places.

Examination of the setal plans of the head capsule and thoracic and abdominal segments of the mature larvæ of the 12 species of borers has revealed certain striking differences in the setal arrangement of the abdominal segments which divide the 12 species primarily into certain groups. The characters that have been found to be of use in this classification are the total number of setae (on one side) in the ninth abdominal segment (excluding the small primaries), the number of setae in the ' pi ' group of Fracker or seta VII of Forbes, in the first, third and seventh abdominal segments. Further division of these groups is based on the arrangement of the crochets on the abdominal (first four) prolegs, the nature and shape of the spiracles, and the position of the trapezoidal tubercles (the chitinized portion around the base of the seta) on the abdomen. It will also be seen that the characters used are easily perceived and the differences enumerated are such as are easily noticed and understood.

A general description of the full-grown larvae of the 12 species of borers in sugarcane is given below :—

Scirpophaga nivella F.

Length 25-35 mm. Breadth at the thickest portion 3-4 mm. Caterpillar cylindrical or slightly flattened dorso-ventrally, thickset or slender, tapering towards the anterior end and blunt towards the posterior. Skin smooth and not well chitinized. Setae small and indistinct. Head small, yellowish brown in colour, mandibles with five teeth, lower ones being pointed. Prothoracic shield not well developed, very light brown in colour. General colour of the thoracic and abdominal segments dirty yellowish white. Dorsal vessel prominently seen through the skin. Spiracles indistinct, elongated vertically, looking like yellowish brown streaks. Crochets on abdominal prolegs uniordinal, arranged in an oval outline.

Argyria sticticraspis Hmpsn.

Length about 25 mm. Breadth at the thickest portion about 3 mm. Caterpillar shows variability in shape, sometimes thickset and sometimes slender, cylindrical generally, sometimes slightly flattened dorso-ventrally. Skin well chitinized, setae stout and well developed. Head prominent, dark brown in colour, mandibles with six teeth rather rounded and blunt. Prothoracic shield well developed, dark blackish brown in colour. Mesothoracic plate is also prominent. Tubercles well developed. Five longitudinal stripes are present on the abdomen, one mid-dorsal, two sub-dorsals and two laterals. The stripes are usually light pinkish brown in colour, sometimes darker. On the abdominal segments, the posterior trapezoidal tubercles more lateral in position than the anterior trapezoidal tubercles. Spiracles open (i.e. there is a clear space inside), elongate oval, with black rims, situated well below the lateral stripes. Crochets on abdominal prolegs multiordinal and arranged in incomplete circles (about three-fourths complete).

Argyria tumidicostalis Hmpsn.

Length about 30 mm. Breadth at the thickest part about 3·5 mm. Caterpillar thickset, slightly blunt at both ends. Skin well chitinized and the setae are short and prominent. Head prominent, dark brown, mandibles with six teeth rather blunt in shape. Prothoracic shield well developed, dark brown in colour. Tubercles on the thoracic and abdominal segments well developed. The posterior trapezoidal tubercles on the abdomen almost in a line with the anterior trapezoidal tubercles. Four longitudinal stripes present on the abdomen, two sub-dorsal and two lateral. Fletcher and Ghosh [1919] record that the markings on the body show the following variations : (1) There may be two broad, slightly pinkish brown stripes on each side of the body, one subdorsal and the other supra-spiracular, (2) the stripes may be indistinct, the tubercles only being prominent on the skin, (3) the tubercles may be indistinct, stripes only being present in an interrupted manner and the two stripes on each side approaching each other at intervals, (4) both stripes and tubercles may be indistinct. Spiracles open (i.e. there is a clear cavity inside), elongate oval, and situated just beneath the lateral stripe. Crochets on the abdominal prolegs multiordinal and form complete circles.

Diatraea auricilia Dudgn.

Length about 25 mm. Breadth at the thickest portion about 2·5 mm. Caterpillar slender, cylindrical, tapering. Skin well chitinized, setae well developed. Head prominent, reddish brown in colour, mandibles with six teeth rather blunt. Prothoracic shield well developed, dull yellowish brown in colour. Tubercles on the thoracic and abdominal segments not well developed. The posterior trapezoidal tubercles on the abdomen more lateral in position than the anterior trapezoidal tubercles. Five longitudinal stripes present on the abdomen, one mid-dorsal, two sub-dorsals, and two laterals. Stripes are reddish brown in colour. Sub-dorsals most prominent, laterals indistinct. Spiracles open (i.e. there is a clear space inside), elongate oval, situated below the lateral stripe. Crochets on the abdominal prolegs multiordinal, and arranged in complete circles.

Diatraea venosata Wlk.

Length about 35 mm. Breadth at the thickest portion about 4 mm. Caterpillar thickset, slightly tapering posteriorly. Skin well chitinized, setae stout and well developed. Head prominent, shiny yellowish brown in colour, mandibles with six teeth, lower ones being pointed. Prothoracic shield well developed, yellowish brown in colour. Tubercles on the thoracic and abdominal segments well developed and are seen as dark bluish black patches on the skin. Four longitudinal stripes present on the abdomen, two sub-dorsals and two laterals. The colour of the stripes pinkish brown. Fletcher and Ghosh [1919] record that in some cases the stripes may be indistinct and in certain other cases again the tubercles may be indistinct. In hibernating larvae both the stripes and tubercles may be indistinct. The anterior and posterior trapezoidal tubercles on the abdominal segments are almost in a line and are situated along the sub-dorsal stripe. Spiracles closed (i.e. there is no clear space inside), broad oval in shape, with blackish rims, and situated along the lower margin of the lateral stripe. Crochets on the abdominal prolegs multiordinal and arranged in complete circles.

Chilo trypetes Bisset.

Length about 35 mm. Breadth at the thickest portion about 3 mm. Caterpillar slender, slightly flattened dorso-ventrally, tapering at both ends. Skin well chitinized and the setae are stout and well developed. Head prominent, light brown in colour, mandibles with six teeth, lower ones being sharply pointed. Prothoracic shield well developed, light brown in colour with patches of dark brown. Four longitudinal stripes are present on the abdomen, two sub-dorsal and two lateral. The sub-dorsal stripes are narrow and light pinkish brown in colour. The lateral ones are broader, very prominent and dark pinkish brown in colour. Spiracles are elongate, bean shaped and lie along the lateral stripe. Crochets on prolegs uniordinal and arranged in slightly more than semicircles.

Chilo zonellus Swinh.

Length about 25 mm. Breadth at the thickest portion about 3 mm. Caterpillar thickset, cylindrical. Skin well chitinized, setae well developed. Head prominent, reddish brown in colour, mandibles with six teeth, lower three being pointed. Prothoracic shield well chitinized and prominent, yellowish brown in colour. Four longitudinal stripes on the abdomen present, two sub-dorsal and two lateral. The stripes are reddish brown in colour. Fletcher and Ghosh [1919] record that the appearance of the caterpillars varies. The common form possesses distinct sub-dorsal brown stripes with tubercles indistinct. In a second form, the sub-dorsal stripes approach one another on the back and practically meet. In a third form, the stripes are rather distinct and tubercles prominent. The posterior trapezoidal tubercles are slightly more lateral in position than the anterior trapezoidal tubercles. Spiracles closed (no clear space inside), elongate oval, and lie along the lower margin of the lateral stripes. Crochets on abdominal prolegs are multiordinal and arranged in complete circles.

Raphimetopus ablutella Zell.

Length about 20 mm. Breadth at the thickest portion about 2·5 mm. Caterpillar thickset, slightly dorso-ventrally compressed. Skin well chitinized, setae slender and very long. Head not very prominent, reddish brown in colour, mandibles with only three lower teeth distinct, which are pointed. Prothoracic shield well developed, greenish in colour. Colour of the other segments of a uniform bluish green, sometimes copperish. Spiracles broad oval in shape with brownish rims. Crochets on abdominal prolegs biordinal and arranged in complete ovals.

Sesamia inferens Wlk.

Length about 30 mm. Breadth at the thickest portion about 3·5 mm. Caterpillar thickset, cylindrical, tapering posteriorly. Skin well chitinized and setae well developed. Head prominent, reddish brown in colour, mandibles with five teeth, lower three being long and pointed. Prothoracic shield well developed, yellowish brown in colour. Colour of the body segments a uniform pink, lighter on the ventral side. Spiracles elongate oval with black rims. Crochets on prolegs uniordinal and arranged in semicircles.

Sesamia uniformis Dudgn.

The description is more or less the same as for *Sesamia inferens* Wlk. (The two species of *Sesamia* could be distinguished in the pupal stage by morphological characters).

Procometis trochala Meyr.

Length about 24 mm. Breadth at the thickest portion about 2 mm. Caterpillar slender, cylindrical, slightly tapering posteriorly. Skin well chitinized and setae well developed. Head prominent, reddish brown in colour, teeth of mandibles undifferentiated. Prothoracic shield well developed, light brown in colour. A number of longitudinal stripes arranged closely on the abdomen, and not very distinct from each other. As many as four can be counted on each side of the mid-dorsal stripe. The stripes are brownish in colour. Spiracles elongate oval, with dark brown rims. Crochets on abdominal prolegs multiordinal and arranged in complete ovals.

Emmalocera depressella Swinh.

Length about 25 mm. Breadth at the thickest portion about 2·5 mm. Caterpillar thickset, cylindrical, slightly tapering posteriorly. Skin well chitinized and setae well developed. Head prominent, yellowish brown in colour, mandibles with only the lower three teeth distinct. Prothoracic shield fairly well developed, light yellowish in colour. Colour of the body segments creamy white without any stripes. Dorsal vessel prominent in some cases. Spiracles rounded oval in shape. Crochets on abdominal prolegs biordinal and arranged in a pear-shaped outline.

KEY FOR THE LARVAE

(Reference Plates XLII—XLV)

Based on the characters mentioned in the text, the classification of the 12 species of borers is as follows :—

1.	Ninth abdominal segment : total number of setae on one side, i.e. between mid-dorsal and mid-ventral line, six (excluding small primaries)	2
	Ninth abdominal segment : total number of setae on one side, i.e. between mid-dorsal and mid-ventral line, eight (excluding small primaries)	8
2.	First abdominal segment : seta VII of Forbes or pi group of Fracker consists of two setae. Crochets on abdominal prolegs : arranged in uni-ordinal series	3
	First abdominal segment : seta VII of Forbes or pi group of Fracker consists of three setae. Crochets on abdominal prolegs : arranged in multi-ordinal series	4
3.	Seventh abdominal segment : seta VII of Forbes or pi group of Fracker consists of one seta. Crochets on prolegs : arranged in semicircles	*Sesamia inferens* Wlk. *Sesamia uniformis* Dudgn.
	Seventh abdominal segment : seta VII of Forbes or pi group of Fracker consists of two setae. Crochets on prolegs : arranged in slightly more than semicircles . .	*Chilo trypetes* Bisset
	Seventh abdominal segment : seta VII of Forbes or pi group of Fracker consists of three setae. Crochets on prolegs : arranged in complete ovals	*Scirpophaga nivella* F.
4.	Crochets on abdominal prolegs : arranged in incomplete circles	*Argyria stictioraspis* Hmpsn.
	Crochets on abdominal prolegs : arranged in complete circles	5
5.	Spiracles : open (i.e. there is a clear space inside) . .	6
	Spiracles : closed (i.e. there is no clear space inside) .	7
6.	Trapezoidal tubercles on the abdomen : anterior and posterior tubercles in a line	*Argyria tumidicostalis* Hmpsn.
	Trapezoidal tubercles on the abdomen : posterior tubercles more lateral than anterior tubercles	*Diatraea auricilia* Dudgn.

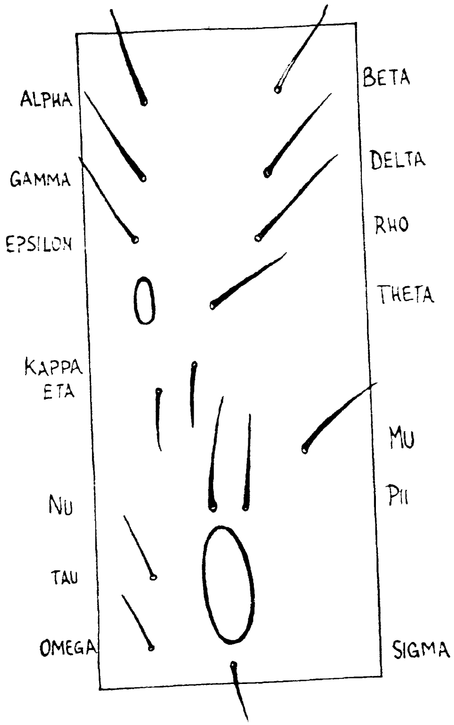


Fig. 1. A hypothetical segment bearing setae in their normal positions

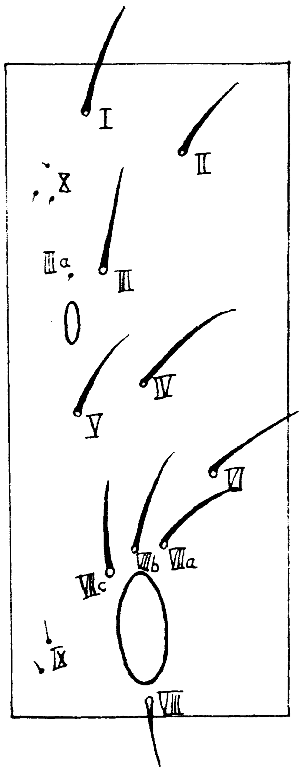
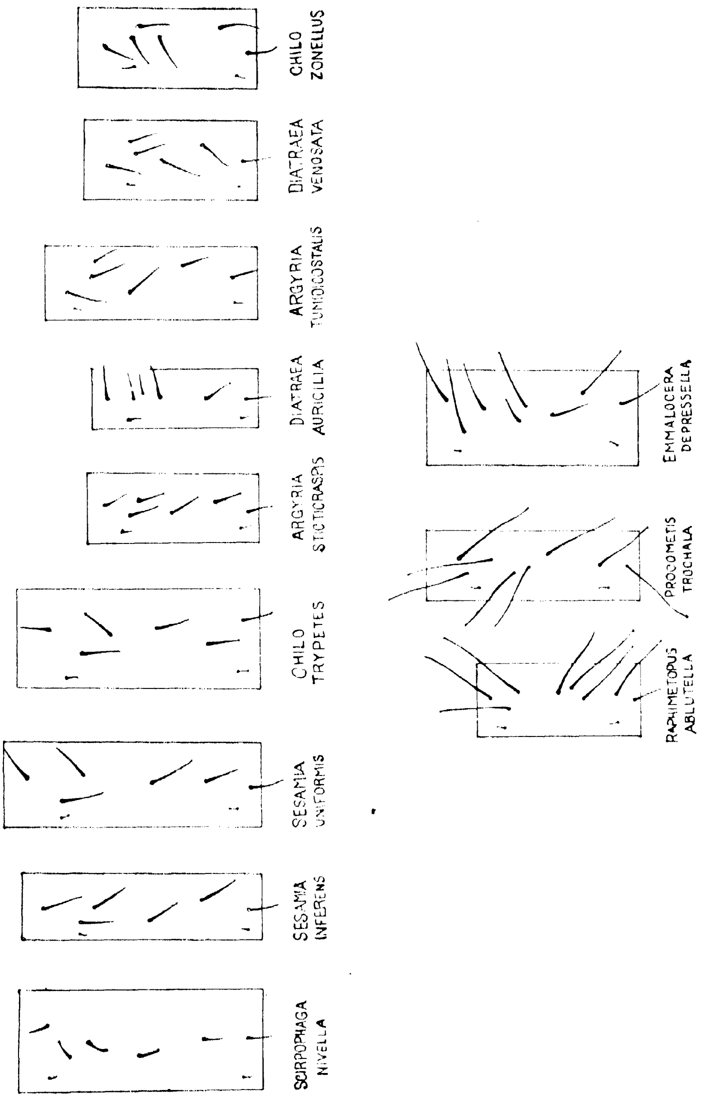
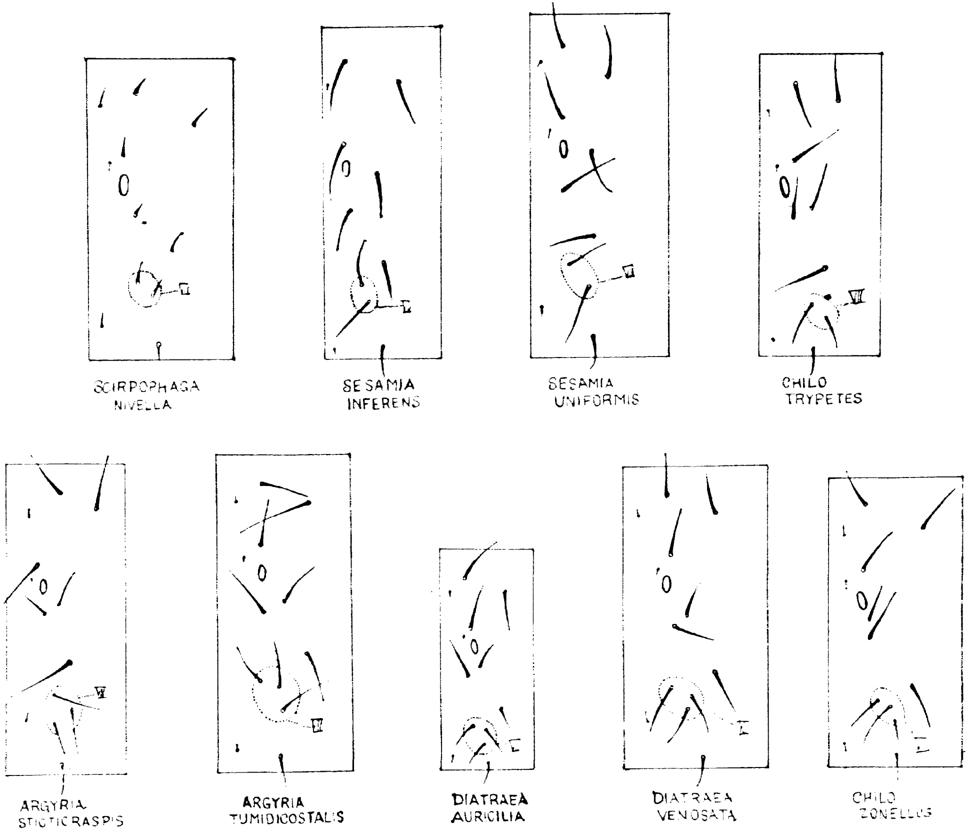


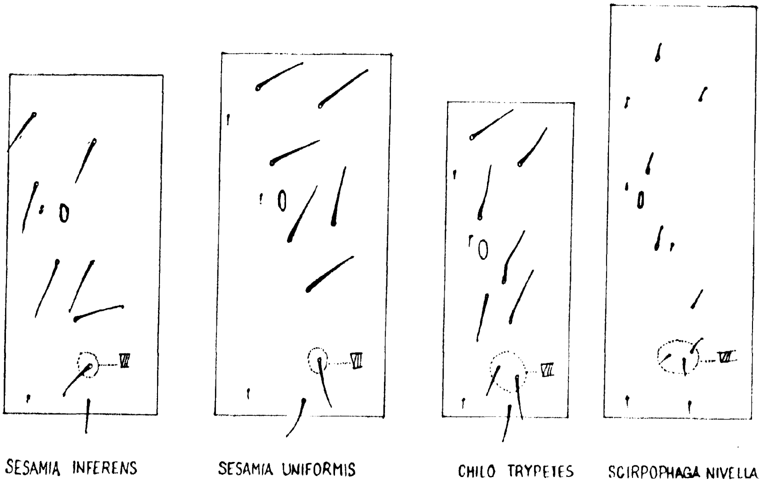
Fig. 2. A typical segment (abdominal) bearing setae



Ninth abdominal segment : setal arrangement (×12)

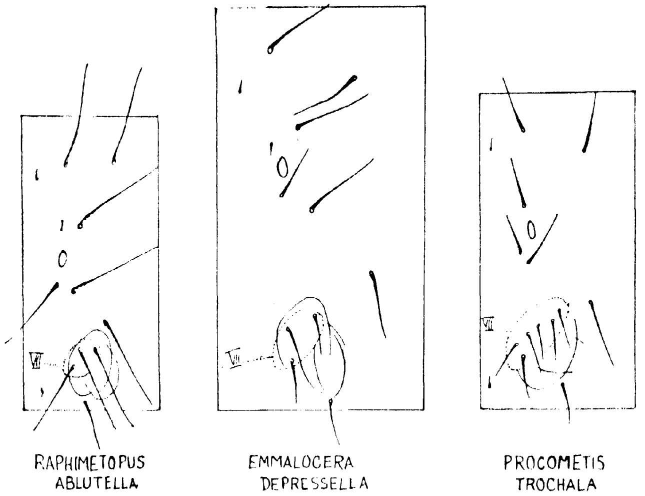


First abdominal segment : setal arrangement (× 12)



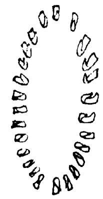
SESAMIA INFERENS SESAMIA UNIFORMIS CHILO TRYPETES SCIRPOPHAGA NIVELLA

FIG. 1. Seventh abdominal segment : setal arrangement (× 12)

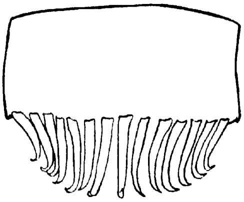


RAPHIMETOPUS ABLUTELLA EMMALOCERA DEPRESSELLA PROCOMETIS TROCHALA

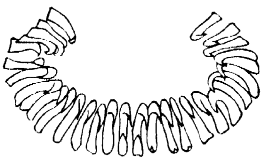
FIG. 2. Third abdominal segment : setal arrangement (× 12)



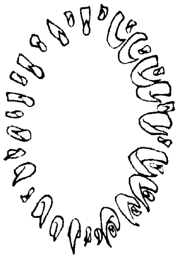
SCIRPOPHAGA NIVELLA.



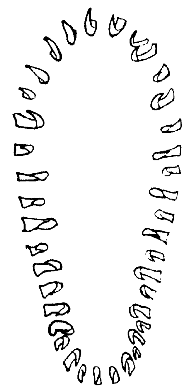
SESAMIA SP.



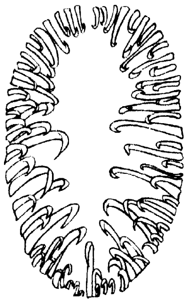
CHILO TRYPETES.



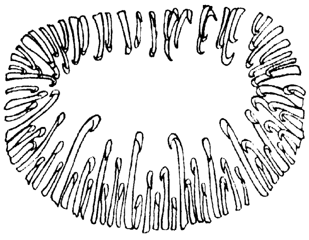
RAPHIMETOPUS ABLUTELLA.



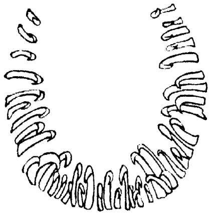
EMMALOCERA DEPRESSELLA.



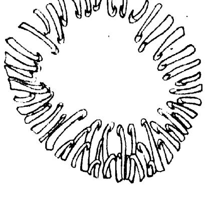
PROCOMETIS TROCHALA.



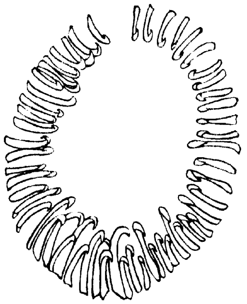
ARGYRIA TUMIDICOSTALIS.



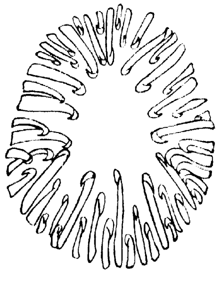
ARGYRIA STICTICRASPIS.



DIATRAEA AURICILIA.



DIATRAEA VENOSATA.



CHILO ZONELLUS.

Crochets on abdominal prolegs (×80)

7.	Spiracles : slightly elongate oval in shape . . .	*Chilo zonellus* Swinh.
	Spiracles : broad oval to round in shape . . .	*Diatraea venosata* Wlk.
8.	Third abdominal segment : seta VII of Forbes or pi group of Fracker consists of five or six setae	*Procometis trochala* Meyr.
	Third abdominal segment : seta VII of Forbes or pi group of Fracker consists of only three setae	9
9.	Crochets on abdominal prolegs : arranged in a broad oval outline	*Raphimetopus ablutella* Zell.
	Crochets on abdominal prolegs : arranged in a pear-shaped outline	*Emmalocera depressella* Swinh.

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REFERENCES

Dyar, H. G. (1893-95). *Ann. N. Y. Acad. Sci.* **8**, 194-232

———— (1901). *Ent. Rec.* **13**, 37-41

Fletcher, T. B. (1927). *Ann. Rept. Impl. Entomologist, Pusa, 1926-27*, pp. 56-67

Fletcher, T. B. and Ghosh, C. C. (1919). *Rept. Proc. Third Entomological Meeting, Pusa*, pp. 368-9 (Also published as *Bulletin No.* **102**, *Agric. Res. Inst., Pusa*)

Forbes, W. T. M. (1910). *Ann. Ent. Soc. Amer.* **3**, 94-132

———— (1916). *J. N. Y. Ent. Soc.* **24**, 137-42

———— (1921). *Ann. Ent. Soc. Amer.* **14**, 344

Fracker, S. B. (1915). *Illinois Biol. Monogr.* **2**, part 2, pp. 1-169 [Also second Edition, revised and reprinted, 1930 (*Contributions from the Ent. Laboratories of the University of Illinois, No.* **43**)]

Ghosh, C. C. (1921). *Rept. Proc. Fourth Entomological Meeting, Pusa* p. 114 (Also published as *Bulletin No.* **134**, *Agric. Res. Inst., Pusa*)

Gupta, B. D. (1940). *Indian J. agric. Sci.* **10**, 781-817

A KEY FOR THE IDENTIFICATION OF THE PUPAE OF THE KNOWN LEPIDOPTEROUS BORERS OF SUGARCANE IN INDIA, BASED ON MORPHOLOGICAL CHARACTERS

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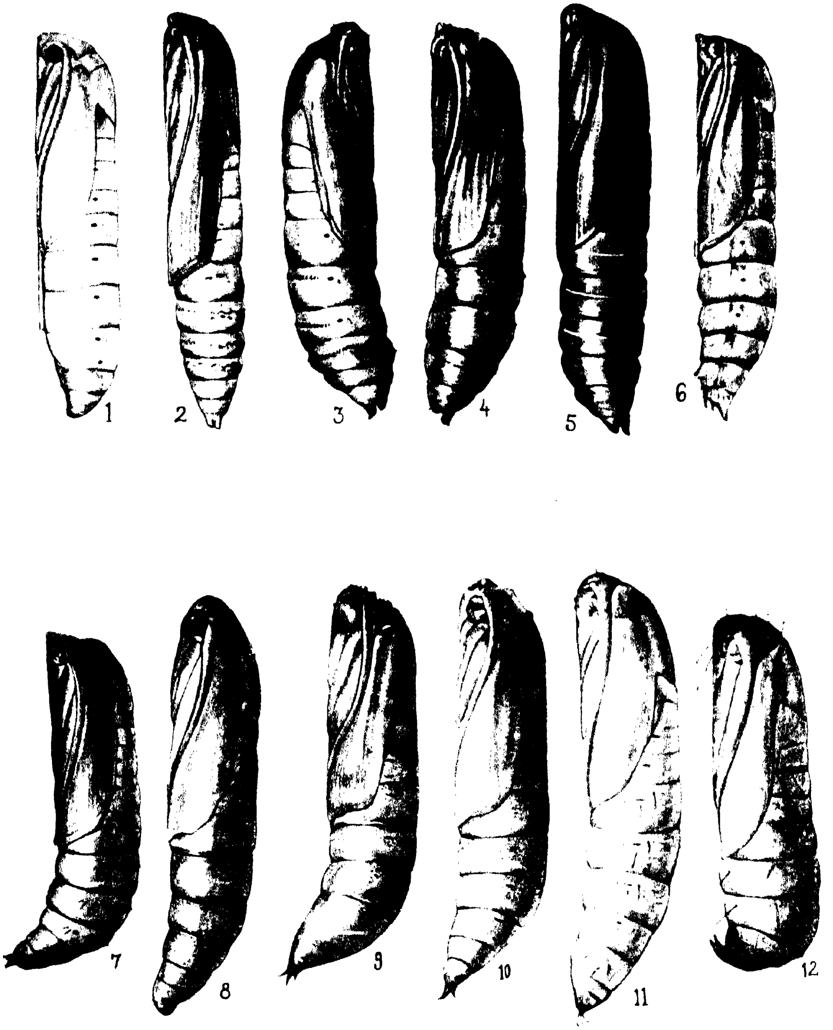
(With Plates XLVI-L)

SCUDDER [1889] was the first to attempt a classification of the Lepidoptera based on pupal characters. His classification was based on the various projections from the body, the cuticular appendages, the colouration and the mode of suspension of the pupa. Chapman [1893-96] and Packard [1895] have made extensive studies on lepidopterous pupae. The most comprehensive work on pupal morphology was published by Mosher [1916, 1917]. She has drawn a classification of the Lepidoptera based on morphological characters of the pupae and has given correct homologies of the different parts of the pupa. Fletcher and Ghosh [1919] and Ghosh [1921] have given keys for the differentiation of pupae of the important borers in sugarcane, rice, etc. in India. Recently, Gupta [1940] has made a study of the anatomy of the different stages of four of the striped borers of sugarcane in India. The following is an attempt to present detailed descriptions of the pupae of all the common caterpillar borers of sugarcane, together with a key for differentiating them in their pupal stage.

PUPAL MORPHOLOGY

All the pupae described here belong to the type known as 'obtected pupa', because all the appendages are firmly soldered to the body wall and have no power of independent movement. They are smooth and rounded and exhibit a hard exterior. The only free segments in both sexes are the fourth, fifth and sixth. A short cremaster (prolongation of the anal segment carrying spines) is generally present. In the case of *Scirpophaga nivella* Fabr. it cannot be called an obtected pupa in the real sense, because all the appendages are not completely soldered to the body wall, the tips being free. A cremaster is absent and the various parts of the body are very lightly chitinized. But as in obtected pupa, *Scirpophaga nivella* has got only the fourth, fifth and sixth abdominal segments free. In *Emmalocera depressella*

SIDEVIEW OF FEMALE PUPAE OF DIFFERENT BORERS (×3)



1. *Scirpophaga nivella* Fabr.; 2. *Argyria sticticraspis* Hamps.; 3. *Argyria tumidicostalis* Hamps.; 4. *Diatraea auricilia* Dudgn.; 5. *Diatraea venosata* Walk.; 6. *Chilo trypetes* Bisset; 7. *Chilo zonellus* Swinh.; 8. *Emmalocera depressella* Swinh.; 9. *Sesamia uniformis* Dudgn.; 10. *Sesamia inferens* Walk.; 11. *Raphimetopus ablutella* Zell.; 12. *Procometis trochala* Meyr.

Swinh., the cremaster is very poorly developed and is reduced to a chitinized transverse ridge on the dorsum of the anal segment. The pupae of the striped borers are characterized by the peculiar form of the short, blunt cremaster and the deep lateral grooves on the tenth segment. The pupa of *Chilo trypetes* Bisset differs from those of the allied striped borers in certain morphological characters. A hypothetical pupa is drawn in Plate XLVII, figs. 1 and 2 to show the different parts of the pupa.

The following is the list of caterpillar borers studied, given under each family and sub-family :—

Name	Family	Sub-family
1. *Scirpophaga nivella* Fabr.	Pyralidae	Schoenobiinae
2. *Argyria sticticraspis* Hmpsn. . . .	,,	Crambinae
3. *Argyria tumidicostalis* Hmpsn. . .	,,	,,
4. *Diatraea auricilia* Dudgn.	,,	,,
5. *Diatraea venosata* Walk.	,,	,,
6. *Chilo trypetes* Bisset	,,	,,
7. *Chilo zonellus* Swinh.	,,	,,
8. *Emmalocera depressella* Swinh. . .	,,	Anerastinae
9. *Sesamia uniformis* Dudgn.	Noctuidae	Acronyctinae
10. *Sesamia inferens* Wlk.	,,	,,
11. *Raphimetopus ablutella* Zell. . . .	Pyralidae	Anerastinae
12. *Procometis trochala* Meyr. . . .	Cryptophasidae	

1. *Scirpophaga nivella* Fabr.

(Plate XLVI, fig. 1 ; Plate XLVII, figs. 3-5)

Pupa appears very delicate and with a soft exterior. Head and maxillae greyish and the rest of the body yellowish-white in colour. Eyepieces are bluish in advanced pupa. Head and appendages are enclosed in a transparent envelope and loosely soldered to the body ; the tips of wings and appendages stand out of the body. Vertex is indicated as a narrow strip and the epicranial suture is fairly distinct. Front is fairly well developed, shining, and more or less flat from above. Clypeus is bulged and rounded. Frontoclypeal suture is indistinct. Labrum is reduced to a small triangular piece and separated from the clypeus. Labial palpi is also very much reduced and indicated as a small piece just above the maxillae. Maxilla very short and is less than one-fifth the length of the wings. Glazed eyepiece is very much narrower than sculptured eyepiece. Genae are prominent and arched. Maxillary palpi are not indicated. Prothoracic legs half as long as the wings. Prothoracic legs extend a trifle between the sculptured eyepieces and antennae. A large portion of femur of the prothoracic leg is exposed. A small portion of femur of the metathoracic leg is also indicated. Mesothoracic spiracles are slit-like and inconspicuous. Mesothoracic legs five-sixths the length of the wings. Metathoracic legs extend beyond the wings and reach almost the caudal margin of the fifth abdominal segment. Abdominal spiracles produced and with slit-like opening and brownish edge. Abdominal segments soft, smooth and without any sculpturings, distinct spines or ridges

Anal end is rounded and a cremaster is absent. In advanced female pupa the pinkish or yellowish anal tuft is clearly seen. Genital opening in the male is a small slit placed on the ninth segment in a slight depression with two elevations on either side. In the female the opening is found on the eighth segment with two raised elevations on either side. Anal opening is in the form of an elongated slit on the ventromeson of the tenth segment. Abdominal segments four, five and six have slight freedom of movement.

Length o female pupa 19-23 mm., greatest width 3-4 mm.

Length of male pupa 14-18 mm., greatest width 2·5-3 mm.

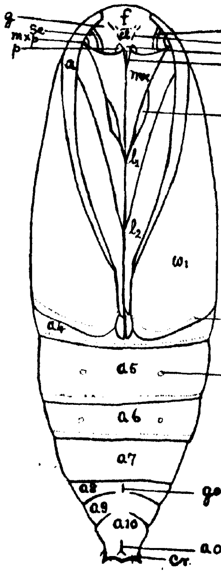
2. *Argyria sticticraspis* Hmpsn.

(Plate XLVI, fig. 2; Plate XLVII, figs. 6-8)

Colour usually yellowish H brown; abdomen lighter in colour. Vertex is indicated as a narrow piece in front of prothorax. Epicranial suture is indicated. Front is concave from above with two horn-like projections on either side above the eyepieces. Fronto-cylpeal suture is indistinct. Clypeus is separated from labrum by a deep furrow. Labial palpi is indicated as a narrow piece between the maxillae. Eyepieces are dark and prominent. Glazed and sculptured eyepieces are almost of equal width. Genae are well developed. Pilifers are small. Maxillae are half the length of the wings. Maxillary palpi present as a small triangulr piece between the eye and the antenna. Antennae are three-fourths the length of the wings. Prothorax is darker, shining and with a median ridge and raised lines on it. Prothoracic legs are about five-eighths the length of the wings. Prothoracic legs do not extend beyond the sculptured eyepiece and antenna. A portion of femur of the prothoracic leg is exposed. Mesothoracic spiracles appear as small, elongated slits with indistinct ridges. Mesothoracic legs less than the wings. Metathoracic legs are as long as the wings. Abdominal spiracles with dark brown rim and clear elliptical openings. Abdominal segments five, six and seven are provided with prominent ridges or flanged plates. These flanged plates are continuous and make a complete circle on segment seven. On segments five and six the flanged plates stop short near the spiracles and are continued ventrally as faint wavy lines. Abdominal segments are covered with numerous minute conical spines. These spines come closer and fuse together to form the flanged plates. These are supposed to prevent the telescoping of the free segments. In addition to these, the caudal margins of segments four, five and six are provided with a network of lightly chitinized ridges. Genital opening in the female is a small slit on the ventral side of the eighth segment. In the male the genital opening is found on the ninth segment with two small raised papillae on either side. Tenth segment is produced into a very short, blunt cremaster with fairly deep lateral grooves. Cremaster consists of dorsal and ventral halves, each carrying two lobes with chitinized edges. Anal opening in the form of a slit terminating in two lines (in the form of an inverted λ). There is freedom of movement between the abodminal segments four and five, five and six, and six and seven.

Length of female pupa 14-16 mm., greatest width 3·5-4 mm.

Length of male pupa 12-14 mm., greatest width 2·5-3 mm.



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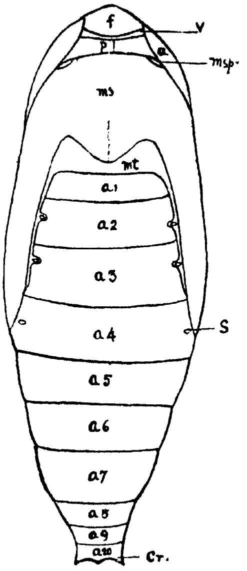

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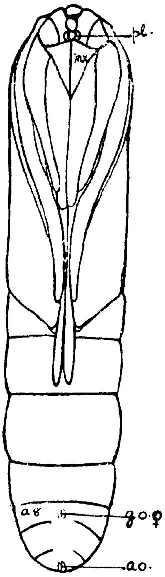

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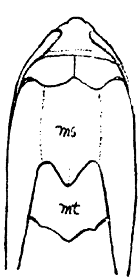

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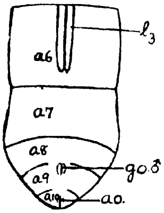

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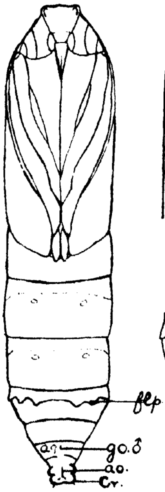

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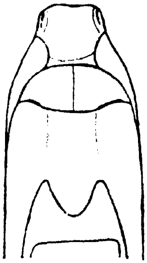

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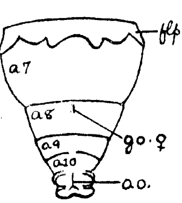

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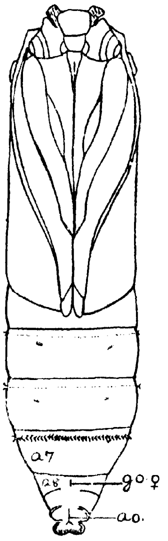

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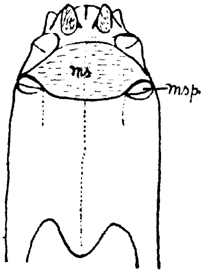

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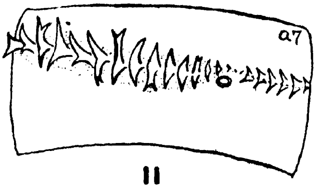

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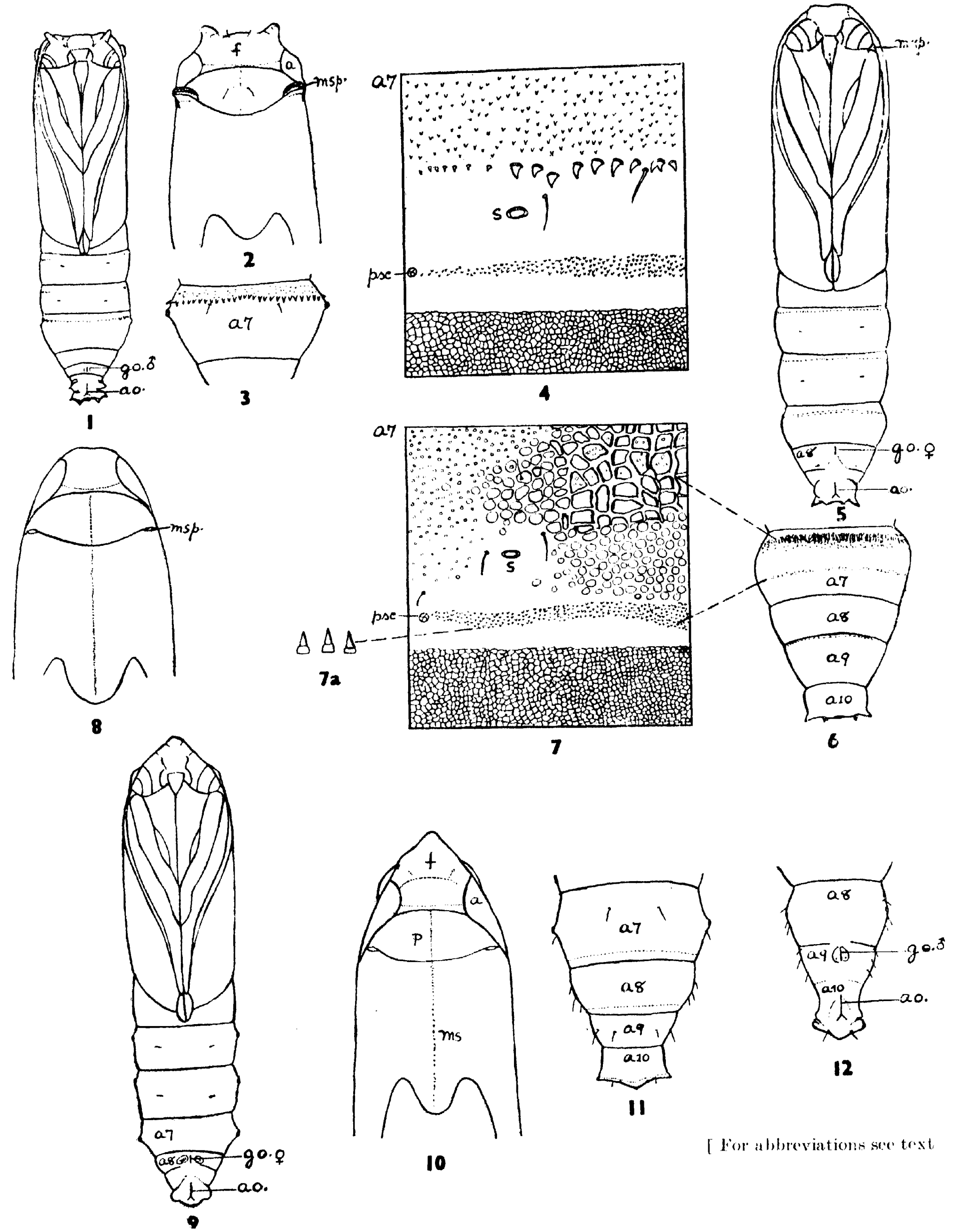
[For abbreviations see text

1. Hypothetical pupa, ventral view; 2. Hypothetical pupa, dorsal view; 3. *Scirpophaga nivella* F., ventral view, female (×4); 4. *Scirpophaga nivella* F., head and thorax, dorsal view, female, (×4); 5. *Scirpophaga nivella* F., anal segment, ventral view, male (×6); 6. *Argyria sticticraspis* H., ventral view, male (×4); 7. *Argyria sticticraspis* H., head and thorax, dorsal view, female (×4); 8. *Argyria sticticraspis* H., anal segment, ventral view, female, (×4); 9. *Argyria tumidicostalis* H., ventral view, female, (×4); 10. *Argyria tumidicostalis* H., head and thorax, female (×4); 11. *Argyria tumidicostalis* H., fifth abdominal segment, side view, enlarged



1. *Diatraea auricilia* Dudgn., ventral view, male (×4); 2. *Diatraea auricilia* Dudgn., head and thorax, dorsal view, male (×6); 3. *Diatraea auricilia* Dudgn., seventh abdominal segment, dorsal view, male (×6); 4. *Diatraea auricilia* Dudgn., fifth abdominal segment, diagrammatic; 5. *Diatraea venosata* Wlk., ventral view, female (×4); 6. *Diatraea venosata* Wlk., anal end, dorsal view, female (×6); 7. *Diatraea venosata* Wlk., fifth abdominal segment diagrammatic; 7a. *Diatraea venosata* Wlk., spines from fifth abdominal segment, highly enlarged; 8. *Diatraea venosata* Wlk., head and thorax, dorsal view, female (×6); 9. *Chilo trypetes* Bisset, ventral view, female (×4); 10. *Chilo trypetes* Bisset, head and thorax, dorsal view, female (×6); 11. *Chilo trypetes* Bisset, anal end, dorsal view, female (×6); 12. *Chilo trypetes* Bisset, anal end, ventral view, male (×6)

3. *Argyria tumidicostalis* Hmpsn.

(Plate XLVI, fig. 3 ; Plate XLVII, figs. 9-11)

Colour yellowish = brown ; face parts and prothorax dark reddish-brown ; abdominal segments shining. Caudal margins of the abdominal segments five to nine are darker in colour. Vertex indicated as a narrow strip bounded cephalad by the epicranial suture. Front well developed and extends upward into two chitinized ridge-like projections. Clypeus distinct and fronto-clypeal suture not indicated. Labrum separated from the clypeus by a faint depression. The invaginations for the anterior arms of the tentorium are indicated. Glazed and sculptured eyepieces are almost of equal width. Pilifers are well developed. Genae are provided with horn-like projections anteriorly, above the eyes. Labial palpi present as a triangular piece in-between the maxillae. Maxillae prominent and half the length of the wings. Maxillary palpi are indicated laterad of the eyes. Antennae three-fourths the length of the mesothorax ; meson with the median ridge and impressed lines over it. Prothoracic legs do not extend cephalad between the sculptured eyepiece and the antennae. A portion of femur of the prothoracic leg is exposed. Mesothorax 1½ times as long as the longest abdominal segment. Mesothoracic spiracles are provided with semi-lunar chitinized ridges caudally. Mesothoracic legs slightly less than the wings. Metathoracic legs as long as the wings. Wings reach the midventer of the fourth abdominal segment. Abdominal spiracles are provided with elliptical openings and dark rim all round. Spiracles on eighth abdominal segment indistinct. Abdominal segments four, five and six are movable in both sexes. Abdominal segments five, six and seven are provided with a more or less complete circle of prominent and distinct double spines. These spines are slightly bent, pointed and highly chitinized. On segments five and six these spines stop short near the spiracle and are continued ventrally as a row of fine tubercles. The spines on segment seven are continuous. All the abdominal segments are beset with numerous transverse rows of minute conical spines. The large double spines are formed as a result of the fusion of these microscopic conical spines. Caudal margins of segments four, five, and six are provided with a network of more or less regular polygonal areas and a band of minute conical spines above them. These together with the large double spines prevent the telescoping of the free segments. Genital opening in the male is a small slit on the ninth segment with two small raised elevations on either side. In the female it is placed on the eighth segment. Anal opening is placed on the tenth segment and is in the form of a slit ending in two lines (λ). Tenth segment carries a very short cremaster with lateral grooves. The dorsal half of the cremaster consists of two short chitinized lobes.

Length of female pupa 16-18 mm., greatest width 4-5 mm.

Length of male pupa 13-15 mm., greatest width 3·5-4 mm.

4. *Diatraea auricilia* Dudgn.

(Plate XLVI, fig. 4 ; Plate XLVIII, figs. 1-4)

Head and thorax reddish-brown and abdominal segments of a dirty brown colour. Front is slightly concave from above. Vertex is reduced to two triangular pieces above the prothorax. Epicranial suture is distinct Pilifers are present. Eyes are dark in colour and the eyepieces are of equal width. Genae are produced into two chitinized horn-like projections on either side above the eyes. Clypeo-labral suture is indicated. Labrum is provided with a notch caudally. Labial palpi is present. Antennae four-fifths the length of the wings. Maxillary palpi present as a small triangular piece laterad of the eyes. Prothoracic legs three-fifths the length of the wings. Prothoracic legs do not extend beyond the eyepieces and antennae. A small portion of the femur of prothoracic leg is seen. Mesothoracic spiracles are provided with very prominent arching tubercles below, which appear like rosettes. These tubercles are covered with very fine microscopic spines. Mesothoracic legs almost as long as the wings. Metathoracic legs slightly longer than the wings. Abdominal spiracles are slit-like, surrounded by reddish brown edges and placed on raised papillae. Caudal margins of the abdominal segments four to six are provided with a network of microscopic chitinized ridges, followed by several rows of minute conical spines. Cephalic margins of segments five to seven are provided with a few microscopic spines. In addition to these, on segments five, six and seven there are incomplete circles of prominent, straight spines, placed apart, mostly on the dorsal and lateral regions nearer the cephalic margins. There is one row of such spines on segments five and six ; sometimes two to three rows on segment seven. Spines on segment seven extend beyond the spiracles to some distance. The slit-like genital opening in the female is placed on the eighth segment. Genital opening in the male is a long slit on the ninth segment. Tenth segment is produced into a short cremaster with lateral grooves ; the dorsal half consists of four spines in two groups of two each and the ventral one carries two spines. Anal opening in the form of a slit ending in two lines (λ) situated on the ventromeson of the tenth segment. Abdominal segments four, five and six exhibit freedom of movement.

Length of female pupa 14-16 mm., greatest width 3-4 mm.

Length of male pupa 10-11 mm., greatest width 2·5-2·75 mm.

5. *Diatraea venosata* Walk.

(Plate XLVI, fig. 5 ; Plate XLVIII, figs. 5-8)

Colour usually dark chestnut-brown. Dorsal side is darker in colour and has a roughened appearance. Head appears more or less flat from above. Vertex is reduced to two small triangular pieces just above the prothorax. Epicranial suture is visible as a faint line. Front is well developed. Fronto-clypeal suture is indistinct. Pilifers and labial palpi are present. Labrum is present as a triangular piece caudad of the clypeus. The invaginations for the anterior arms of the tentorium are indicated. Glazed and sculptured eyepieces are almost of equal width. Face parts and the limbs have a finely pitted appearance. Maxillae half the length of the wings. Maxillary palpi are present. Antennae four-fifths the length of the wings. Mesothoracic legs less than the wings. Mesothoracic spiracles provided with slit-like opening and reddish brown edge. Abdominal segments one to seven are provided with a network of irregular chitinized ridges towards the margins which present a roughened appearance. On segments four to seven the irregular chitinized ridges towards the dorso-cephalic margins are highly chitinized and very prominent. The ridges on the caudal margins of segments four to six are very regular and consist of rows of polygonal areas. In addition, on segments one to seven, just above the chitinized ridges, there are several rows of minute conical spines. These spines on segments four to six appear as glistening white streaks, in fresh specimens. Segments eight and nine are provided with numerous minute spines. Proleg scars are indicated on abdominal segments five and six. Genital opening in the female is a small slit near the cephalic margin of the eighth segment. In the male it is found on the ninth segment. Anal segment is produced into a very short, blunt cremaster with lateral grooves. The dorsal half of the cremaster carries four spines, two large and two small, in two groups of two each on either side. The ventral half is fairly smooth and rounded. Anal opening is in the form of a slit ending in two lines (λ) on the tenth segment. Abdominal segments four, five and six are free.

Length of female pupa 17·5-19 mm., greatest width 3·5-4 mm.

Length of male pupa 12·5-13·5 mm., greatest width 2·5-3 mm.

6. *Chilo trypetes* Bisset

(Plate XLVI, fig. 6; Plate XLVIII, figs. 9-12)

Pupa appears elongated and slender. Head, thorax and appendages yellowish=brown. Abdomen lighter in colour, with broad reddish-brown stripes along the spiracular region on either side. Face parts, appendages and thoracic segments appear shining and the rest of the body rather dull in appearance. Vertex is present as a narrow strip. Epicranial suture is visible. Front is produced anteriorly and appears as a conical horn-like projection from above. The fronto-clypeal suture is indistinct. Labrum is represented by a narrow strip between the eyes. Labial palpi not indicated. Glazed and sculptured eyepieces are almost of equal width. Pilifers are present. Maxillae half the length of the wings. Gena indicated as a smooth area above the eyes. Maxillary palpi present as small areas laterad of the eyes. Median ridge on the thorax is very prominent. Prothoracic legs five-eighths the length of the wings. Mesothoracic legs slightly shorter than the wings. Mesothoracic spiracles slit-like. Metathoracic legs slightly longer than the wings and reach the middle of the fourth abdominal segment. Abdominal segments are provided with numerous microscopic conical spines. These spines are more numerous towards the caudal margins of segments four to six. The body setae are very prominent on the abdominal segments. Genital opening in the female is a small slit extending from about the middle of the eighth abdominal segment to the cephalic margin of the ninth abdominal segment. The opening is placed in a slight depression with two brownish, prominent tubercles on either side. In the female it is placed on the caudal margin of the ninth segment with two brownish tubercles on either side. Anal segment is produced into a very short, blunt cremaster with lateral grooves. The dorsal half of the cremaster consists of a broad ridge with three indistinct spine-like lobes. The ventral half is fairly smooth and without any spines. Anal opening is in the form of a slit ending in two lines (λ) on the ventromeson of the tenth segment. Proleg scars are indicated on segments five and six. There is freedom of movement between segments four and five, five and six, and six and seven.

Length of female pupa 15-18 mm., greatest width 3·5-4 mm.

Length of male pupa 13-13·5 mm., greatest width 2·5-3 mm.

7. *Chilo zonellus* Swinh.

(Plate XLVI, fig. 7 ; Plate XLIX, figs. 1-3)

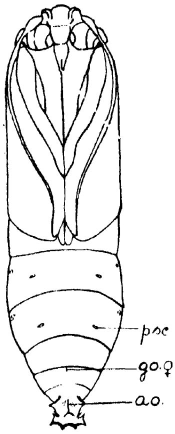
Pupa appears bent. Colour usually reddish-yellow. Eyes darker in colour. Vertex shining and indicated as a narrow strip. Epicranial suture is distinct. Front is flat from above and slightly produced anteriorly. Clypeus is prominent and slightly bulged out. Fronto-clypeal suture is indistinct. The invaginations for the anterior arms of the tentorium indicated. Labrum is separated from the clypeus by a deep furrow. Eye-pieces are of almost equal width. Pilifers and maxillary palpi are indicated. Genae are produced above into two horn-like ridges with shallow depressions in the centre. Labial palpi are present. Maxillae half the length of the wings. Prothorax about one-third the length of the mesothorax ; reddish in colour and with a median ridge and indefinite elevated lines on it Prothoracic legs five-eighths the lenghth of the wings. A portion of the prothoracic femur is exposed. Mesothorax shining, and with impressed lines on it. Mesothoracic legs almost as long as the wings. Mesothoracic spiracles with reddish elevated ridges, caudally. Metathoracic legs slightly longer than the wings. Wings reach almost the caudal margin of the fourth abdominal segment. Abdominal segments smooth, shining. Abdominal spiracles with slit-like opening and slightly raised reddish rim. Abdominal segments are provided with numerous rows of microscopic conical spines. Caudal margins of segments four to six are provided with a network of more or less regular polygonal areas. In addition, the cephalic margins of segments five to seven are provided with six to nine rows of prominent, short, conical spines, which stop short near the spiracle. These spines are quite different from those of *Diatraea auricilia* Dudgn. in structure and arrangement. The spines here are not distinct and separate as in *D. auricilia* and moreover are arranged in more than one row. The margins of these segments present a rough appearance due to the presence of these spines. Proleg scars are seen on segments five and six. Anal segment is provided with a short, blunt, cremaster with deep lateral grooves. Cremaster consists of a dorsal half with six short spines, in two groups of three each, arranged in a triangle on either side. Genital opening in the female is a small slit near the cephalic margin of the eighth segment. In the male the genital opening is placed on the ninth segment with raised papillae on either side. Anal opening is in the form of a slit terminating in two lines (λ) on the tenth segment. Abdominal segments four to six are free in both sexes.

Length of female pupa 12·5-17 mm., greatest width 3-4 mm.

Length of male pupa 10·5-13 mm., greatest width 2·5-3 mm.

PLATE XLIX

1. ***Chilo zonellus*** Swinh., ventral view, female (×4); 2. ***Chilo zonellus*** Swinh., head and thorax, dorsal view, female (×6); 3. ***Chilo zonellus*** Swinh., anal segment, dorsal view, female (×6); 3a. ***Chilo zonellus*** Swinh., spines from fifth abdominal segment, highly magnified; 4. ***Emmalocera depressella*** Swinh., ventral view, female (×4); 5. *Emmalocera depressella* Swinh., head and thorax, dorsal view, female (×4); 6. *Emmalocera depressella* Swinh., anal end, ventral view, male (×4); 7. ***Emmalocera depressella*** Swinh., anal end, dorsal view, female (×4); 8. ***Emmalocera depressella*** Swinh., fifth abdominal segment, diagrammatic; 8a. *Emmalocera depressella* Swinh., 'pits' from abdominal segment, highly enlarged; 9. *Sesamia uniformis* Dudgn., ventral view, female (×4); 10. *Sesamia uniformis* Dudgn., anal end, side view, female (×6); 11. *Sesamia inferens* Wlk., ventral view, male (×4); 12. *Sesamia inferens* Wlk., head and thorax, dorsal view, female (×6); 13. *Sesamia inferens* Wlk., anal end, side view, female (×6); 14. *Sesamia inferens* Wlk., fifth abdominal segment, diagrammatic; 14a. *Sesamia inferens* Wlk., 'pits' from abdominal segments, highly magnified



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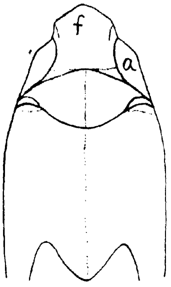

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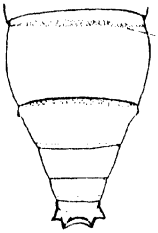

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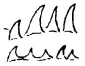

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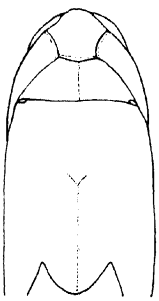

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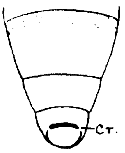

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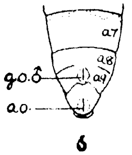

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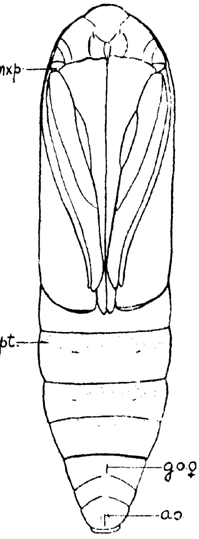

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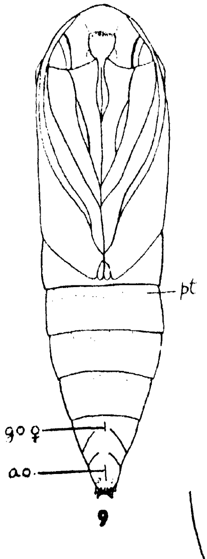

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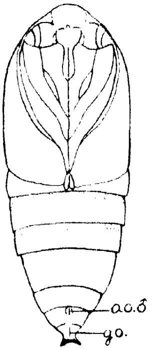

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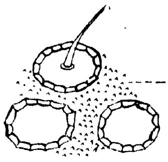

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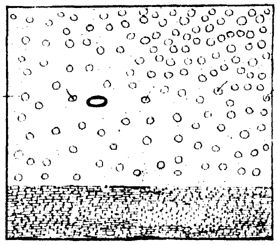

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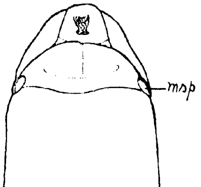

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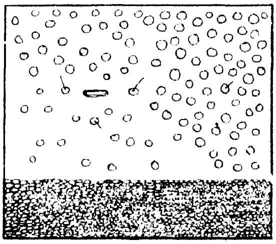

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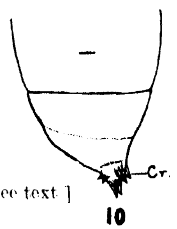

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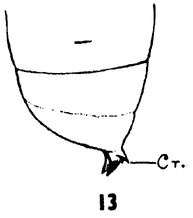

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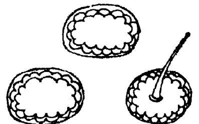

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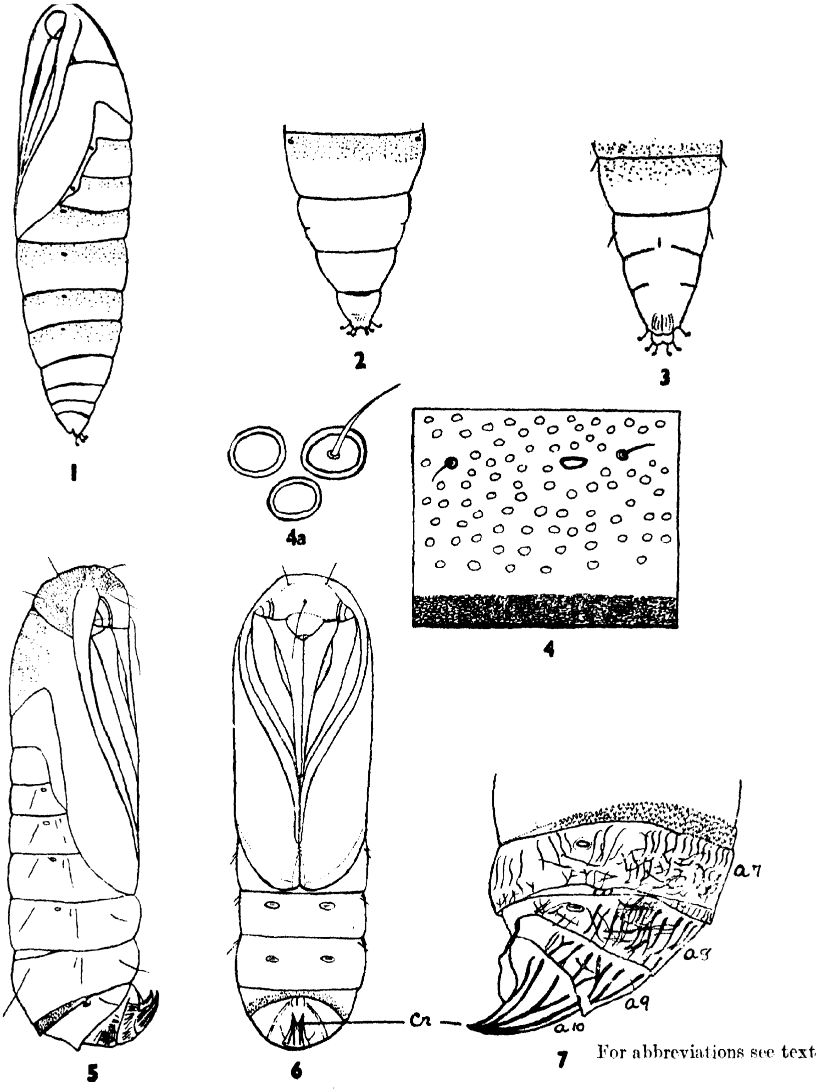
For abbreviations see text]



1. *Raphimetopus ablutella* Zell., side view., female (×4); 2. *Raphimetopus ablutella* Zell., anal end, dorsal view, female (×6); 3. *Raphimetopus ablutella* Zell., annal end, ventral view, female (×6); 4. *Raphimetopus ablutella* Zell., abdominal segment, diagrammatic; 4a. *Raphimetopus ablutella* Zell., 'pits' from abdominal segment, highly enlarged; 5. *Procometis trochala* Meyr., side view, female (×4); 6. *Procometis trochala* Meyr., ventral view, female (×4); 7. *Procometis trochala* Meyr., anal end, side view (×8)

8. *Emmalocera depressella* Swinh.

(Plate XLVI, fig. 8 ; Plate XLIX, figs. 4-8)

General colour is yellowish-brown. Cephalic margins of abdominal segments reddish-brown and pitted in appearance. Face parts and thorax shining and with impressed lines. Vertex is very much reduced and indicated as two triangular pieces on the inner side of the antennae. Epicranial suture is distinct. Front is smooth, rounded and slightly arched. Clypeus is well developed and the fronto-clypeal suture is indistinct. The fronto-clypeus is provided with a few transverse ridges. The clypeo-labral suture is also indicated. Pilifers are present. Glazed eyepiece is narrower than sculptured eyepiece. Genae are represented as smooth areas. Labial palpi are present. Maxillae are long, more than three-fourths the length of wings. Maxillary palpi are indicated as two large pieces latered of the eyes. Antennae shorter than maxillae. Prothoracic legs are half the length of the wings. Mesothoracic spiracles appear as small slits bounded caudally by small ridges. Mesothoracic legs shorter than wings. Metathoracic legs as long as the wings. Abdominal spiracles with elliptical opening and reddish rim. Abdominal segments one to nine are provided with numerous minute conical spines. In addition, the metathoracic segment and the first seven abdominal segments are provided with numerous oval ‘ pits ’, which are more numerous towards the cephalic margins of the free segments four, five and six. The body setae arise from the centre of these pits ; each pit consists of a shallow depression in the middle and a chitinized rim all round. The rim appears to be made up of a number of flattened spines fused together. Besides these, the caudal margins of the abdominal segments four, five and six are provided with a network of ridges. Genital opening in the male is slit-like and placed in a shallow depression on the ninth segment with two small, raised elevations on either side. In the female the genital opening is found on the eighth segment. Anal opening is long and slit-like, and does not end in two lines as in the case of the striped borers. The dorsal part of the hind end of the pupa is rounded, smooth and with a transverse, chitinized ridge which represents the cremaster. There are no distinct spines or projections on the anal segment. Abdominal segments four, five and six are free.

Length of female pupa 15-17·5 mm., greatest width 3·5-5 mm.

Length of male pupa 10-13 mm., greatest width 2·5-3·5 mm.

9. *Sesamia uniformis* Dudgn.

(Plate XLVI, fig. 9 ; Plate XLIX, figs. 9 and 10)

Head and thorax dark reddish-brown ; abdomen yellowish-brown. Body much wider at the cephalic end and tapering gradually to the caudal end of the body. Vertex is very much reduced and indicated as two small triangular pieces. Fronto-clypeal region has a rough appearance. Front is provided with a chitinized oval tubercle in the middle. Fronto-clypeal suture is distinct. Clypeus is provided with a small globular tubercle on the caudal margin. Clypeo-labral suture is distinct. Pilifers and genae indicated. Sculptured eyepiece broader than glazed eyepiece. Labial palpi present as a long piece between the maxillae. Maxillae long and five-eighths the length of the wings. Prothoracic legs extend a little beyond the sculptured eyepieces and antennae. Prothoracic legs are less than the maxillae. Mesothoracic legs seven-eighths the length of wings. Mesothoracic spiracles slit-like and with prominent oval, flattened tubercles, adjacent to their caudal margins. Metathoracic legs as long as the wings. A part of the prothoracic femur is exposed. Abdominal spiracles are elongated and slit-like. Abdominal segments one to eight, sometimes one to nine, with numerous oval 'pits', which are more numerous on the cephalic margins of the free abdominal segments four to six. Each pit consists of a shallow depression in the centre and a chitinized rim all round. The rim is made up of concentric rings of spine-like ridges. The body setae are always associated with the pits, as in *Emmalocera depressella*. Genital opening in both the sexes is found on the ninth abdominal segment in the form of an elongated slit. Anal opening is slit-like. Anal segment is produced into a distinct cremaster, which consists of a concave ventral portion carrying four spines at its tip and a straight dorsal portion with two spines at some distance apart. Abdominal segments four to six are free.

Length of female pupa 15-17·5 mm., greatest width 3·5-5 mm.

Length of male pupa 10-13 mm., greatest width 2·5-3·5 mm.

10. Sesamia inferens Walk.

(Plate XLVI, fig. 10; Plate XLIX, figs. 10-14)

Anal segment is produced into a distinct cremaster with a stalk, carrying four spines at its tip, two small and two big. Except for this distinct difference in the cremaster both the pupae of *Sesamia inferens* and *Sesamia uniformis* appear to be alike in the disposal of the different morphological structures.

Length of female pupa 15·5-17·5 mm., greatest width 3-4·5 mm.

Length of male pupa 10·5-12 mm., greatest width 2·5-3 mm.

11. Raphimetopus ablutella Zell.

(Plate XLVI, fig. 11; Plate L, figs. 1-4)

General colour is greenish brown. Abdominal segments are lighter in colour and have a pitted appearance due to the presence of numerous oval pits. The body is much wider at the cephalic end, gradually tapering towards the hind end. Mesothoracic spiracles are slit-like. Abdominal spiracles are provided with elliptical openings and slightly raised reddish rim. Abdominal segments one to seven are provided with numerous oval pits, which are more numerous towards the cephalic margins. These pits are quite different in structure from those of *Emmalocera depressella* Swinh. or *Sesamia* spp. The setae on the abdominal segments are always associated with these pits. Except for these pits, the abdominal segments are devoid of any prominent ridges or spines. Anal segment is made up of a lightly chitinized dorsal half, with two lobes pointing posteriorly and carrying six to ten long, brownish, circinate hairs. A transverse chitinized ridge is present on the cephalic margin of the dorsum of the anal segment. Anal opening is slit-like and situated on the ventromeson of the tenth segment. Genital opening in the female is slit-like and placed on ventromeson of the ninth segment. Abdominal segments four, five and six are free in both sexes.

Length of female pupa 10-14 mm., greatest width 3·5-4 mm.

12. *Procometis trochala* Meyr.

(Plate XLVI, fig. 12; Plate L, figs. 5-7)

Pupa appears dark brown in colour and more or less cylindrical in shape. Head and thorax are rugose in appearance owing to the presence of fine ridges. Epicranial suture is distinct. Front is flat from above and carries two prominent setae on either side. Fronto-clypeal suture is indicated. Clypeus is well developed, with a long seta rising from the centre of it. A visible labial palpi is not indicated. Pilifers, genae and maxillary palpi are indicated. Prothoracic and mesothoracic legs do not extend between the eyes and antennae. Maxillae well developed and two-thirds the length of the wings. Prothoracic legs about half the length of the wings. Mesothoracic legs slightly less than the maxillae in length. Antennae seven-eighths the length of the wings. Metathoracic legs as long as the wings. Mesothoracic spiracles indistinct. Abdominal spiracles are provided with oval slits. Cephalic margins of abdominal segments are provided with an anastomosing network of chitinized ridges, which present a rough appearance. Caudal margins of segments three, four and five are provided with lightly chitinized, raised polygonal areas. In addition to these, the caudal margin of segment five has five to seven rows of pointed spines. Abdominal setae are very long and prominent. The last abdominal segments, seven to ten, are highly chitinized and with very prominent ridges. Anal segment is produced into a distinct cremaster, which consists of a pair of stout, prominent spines bent ventrally and joined at their bases. These spines are provided with prominent longitudinal ridges. Genital opening in both the sexes is in the form of an elongated slit on the ventromeson of the ninth abdominal segment. Anal opening is slit-like and placed on the ventral side of the anal segment. Abdominal segments four, five, and six are free.

Length of female pupa 11-14 mm., greatest width 3-4 mm.

Length of male pupa 10-11 mm., greatest width 2·5-3 mm.

KEY TO PUPAE OF BORERS

1.	Pupa with soft exterior; appendages partially soldered to the body; the tips of legs and wings free. Cremaster absent . . .	*Scirpophaga nivella* Fabr.
	Pupa with hard exterior; appendages soldered down to the body to form a smooth exterior. Cremaster present	2
2.	Pupa with short blunt cremaster and deep lateral grooves on the tenth abdominal segment. Anal opening in the form of slit ending in two lines (人)	3
	Pupa with rounded and smooth anal end. Cremaster reduced and represented by a chitinized transverse ridge on the dorso-cephalic margin of the anal segment. Cephalic margins of abdominal segments with 'pits' and microscopic conical spines in between. Anal opening slit-like	7

	Pupa with a distinct cremaster, with or without a distinct stalk. No lateral grooves on the tenth abdominal segment. Anal opening slit-like	8
3.	Without ridges, distinct hooks or roughness on abdominal segments. Dorsal half of anal end with three indistinct spine-like projections posteriorly	*Chilo trypetes* Bisset.
	With ridges, hooks or roughness on abdominal segments five, six and seven . . .	4
4.	With incomplete circle of roughness on the cephalic margin of abdominal segments. Dorsal half of anal end with four spines, in two groups of two each, pointing posteriorly	*Diatraea venosata* Walk.
	With complete circle of ridges or spines on the cephalic margin of abdominal segment seven	5
	With incomplete circle of spines on the cephalic margin of abdominal segment seven .	6
5.	Circle made up of flattened ridges (flanged plates) more or less joined together . .	*Argyria sticticraspis* Hmpsn.
	Circle made up of distinct and separate double spines	*Argyria tumidicostalis* Hmpsn.
6.	Spines on segment seven quite distinct and separate and extend beyond the spiracles. Dorsal half of anal end with four spines and the ventral with two spines . . .	*Diatraea auricilia* Dudgn.
	Spines on segment seven not quite distinct and separate and do not extend beyond the spiracles. Dorsal half of anal end with six short spines in two groups of three each on either side	*Chilo zonellus* Swinh.
7.	Anal end without any lobes or hairs . .	*Emmalocera depressella* Swinh.
	Anal end with two lobes dorsally, which carry six to ten long, circinate hairs . . .	*Raphimetopus ablutella* Zell.
8.	Cephalic margins of abdominal segments with 'pits'	9
	Cephalic margins of abdominal segments with anastomosing chitinized ridges. Anal segment with a pair of stout, pointed spines, bent ventrally and joined at their bases .	*Procometis trochala* Meyr.
9.	Anal segment with a stalk carrying four spines, two small and two large	*Sesamia inferens* Walk.
	Anal segment with a ventral portion carrying four spines and a dorsal portion with two spines, six in all	*Sesamia uniformis* Dudgn.

ACKNOWLEDGEMENTS

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REFERENCES

Chapman, T. A. (1893). *Trans. ent. Soc. London*, pp. 97-119; 255-65

————————(1894). *Trans. ent. Soc. London*, pp. 335-50

————————(1896). *Trans. ent. Soc. London*, pp. 129-47

Fletcher, T. B. (1928). *Report of the Imperial Entomologist, Sci. Rept. Agric. Res. Inst. Pusa, 1926-27*, pp. 56-67

Fletcher, T. B. and Ghosh, C. C. (1919). *Rept. Proc. Third ent. Meeting, Pusa,* pp. 368-9 (Also published as *Bull. No.* **102**, *Agric. Res. Inst., Pusa*)

Ghosh, C. C. (1921). *Rept. Proc. Fourth ent. Meeting Pusa*, p. 114 (Also published as *Bull. No.* **134**, *Agric. Res. Inst., Pusa*)

Gupta, B. D. (1940). *Indian J. agric. Sci.* **10,** 787-817

Mosher, E. (1916). *Bull. Illinois State Lab. Nat. Hist.* **12,** 1-159

—————— (1917). *Maine Agric. Expt. Stn. Bull. No.* **259**

Packard, A. S. (1895). *Mem. Nat. Acad. Sci.* **7,** 56-83

Scudder, S. H. (1889). *The Butterflies of the Eastern United States and Canada* (3 Vols.)

LIST OF ABBREVIATIONS USED IN PLATES XLVII-L

a = antenna
al — a 10 = abdominal segments 1-10
ao. = anal opening
at. = invaginations for the anterior arms of the tentorium
ct. = clypeus
cm. = cephalic margin of abdominal segments
cr. = cremaster
es. = epicranial suture
f. = front
fl. = femur of prothoracic leg
fcs. = fronto-clypeal suture
fp. = flanged plate
g. = gena
ge. = glazed eyepiece
go. = genital opening
lb. = labrum
l_1 = prothoracic leg
l_2 = mesothoracic leg
l_3 = metathoracic leg
lp. = labial palpi
ms. = mesothorax
msp. = mesothoracic spiracle
mt. = metathorax
mp. = maxillary palpi
mx. = maxilla
p. = prothorax
pl. = pilifers
psc. = proleg scar
pt. = ‘ pits ’
s. = spiracle
se. = sculptured eyepiece
v. = vertex
w_1 = mesothoracic wing
w_2 = metathoracic wing

SCALE INSECTS OF THE PUNJAB AND NORTH-WEST FRONTIER PROVINCE USUALLY MISTAKEN FOR SAN JOSÉ SCALE (WITH DESCRIPTIONS OF TWO NEW SPECIES)

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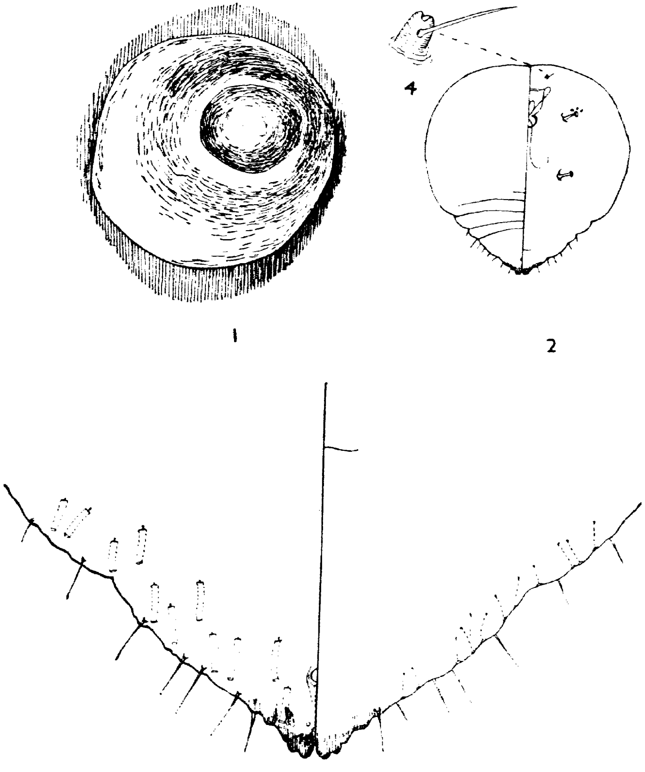
(With Plates LI—LIII)

THE Imperial Council of Agricultural Research, India, sanctioned a scheme, in April 1937, for three years to carry out a survey of the Punjab and the N.-W. F. Province in order to find out the distribution and food-plants of San José scale, a well-known pest of deciduous fruit trees in many parts of the world [Rahman, 1940]. This survey has brought to light the existence of a number of economic Coccidae—including two new species—which closely resemble San José scale either in their morphology or symptoms of their attack, and as such are usually mistaken for it. This paper is an attempt to bring together briefly the differentiating structural and other peculiarities of these forms with a view to ensuring their correct identification.

TENTATIVE KEY TO DIFFERENTIATE THE SPECIES RECORDED IN THIS PAPER

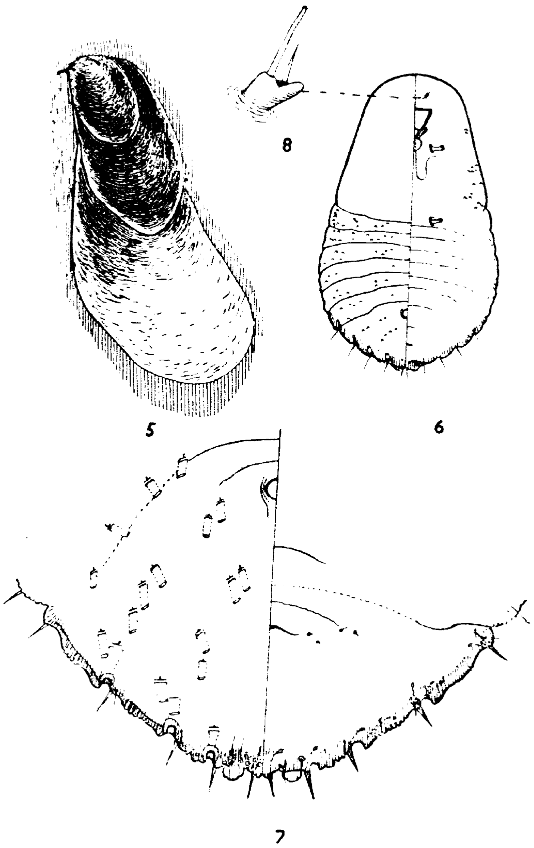
1 (14) One-barred dorsal ducts present
2 (13) Never enclosed in puparium
3 (12) Pygidium with paraphyses or densariae
4 (11) Pygidium with three well-developed lobes
5 (10) Thoracic tubercles absent
6 (9) Ventrum without perivulvar pores
7 (8) Ventrum with three scleroses....*Aonidiella aurantii* (Mask.)
8 (7) Ventrum with one sclerosis......*Aonidiella citrina* (Coq.)
9 (6) Ventrum with five groups of perivulvar pores......*Aonidiella orientalis* (Newst.)
10 (5) Thoracic tubercles present.... .....*Chrysomphalus ficus* Ashm.
11 (4) Pygidium with two well-developed and one poorly developed lobes.......*Quadraspidiotus* (*Aspidiotus*) *perniciosus* (Comst.)
12 (3) Pygidium without paraphyses or densariae......*Aspidiotus destructor* Sign.
13 (2) Always enclosed in II stage nymphal skin......*Aonidia zizyphi* sp. n. (Plate LI, figs. 1-4)
14 (1) Two-barred dorsal ducts present
15 (18) Ventrum with perivulvar pores

Aonidia zizyphi



1. Female scale ; 2. Female ; 3. Pygidium ;
4. Antenna of adult female

Lapazia peshawarensis



5. Female scale ; 6. Female ; 7. Pygidium ;
8. Antenna of adult female

16 (17) Ventrum with five groups of perivulvar pores......*Parlatoria oleae* (Colv.)

17 (16) Ventrum with four groups of perivulvar pores......*Parlatoria pseudopyri* Kuw.

18 (15) Ventrum without perivulvar pores ...*Lapazia peshawarensis* sp. n. (Plate LI, figs. 5-8)

Identifications were confirmed by Dr R. Takahashi of Agricultural Research Institute, Taihoku, Formosa, through the British Museum, London.

1. *AONIDIELLA AURANTII* (MASK.) ; CALIFORNIA RED SCALE

Newstead, R. 1901 Mon. Brit. Cocc. *London,* I : 88

Distribution

Punjab.—Ahmadgarh (Malerkotla State), Ambala, Alipur, Cambellpur, Changamanga, Dasua, Gangapur, Gobindgarh (Nabha State), Gujranwala, Gujrat, Gutkar (Mandi State), Jhelum, Jind, Kahuta, Kalka, Kotgarh, Lahore, Lyallpur, Malerkotla, Montgomery, Multan, Muzaffargarh, Nabha, Phagwara, Sangrur (Jind), Sargodha, Sialkot, Taxila, Una.

N.-W. F. Province.—Bannu, Charsadda, Darband, Darsamand, D. I. Khan, Gardi, Ghoriwala, Jamal-garhi, Kohat, Mardan, Peshawar, Phulera State, Tarujabba, Thall, Thana and Totkan (Malakand Agency) and Totkas.

It has also been recorded from Ceylon, Coimbatore, Dhamdha, Godavari-Palghat, Pusa, and Someshwaram in South Kanara [Ramachandran and Ayyar, 1934].

Food plants

It is abundant on leaves, bark and fruit of *Citrus* spp. (*chakotra*, *galgal*, grape-fruit, *kimb*, lemon, Malta, oranges, etc.) (Plate LII, fig. 1). It has also been found fairly abundant on *Aegle marmelos*, *Agave* sp., *A. variegata*, *Aloe vera*, *Alstonia scholaris*, *Bauhinia alba*, *B. racemosa*, *Bombax malabaricum*, *Broussonetia papyrifera*, *Canna indica*, *Cassia fistula*, *Cassia* sp., *Cordia myxa*, *Diospyros montana*, *Dombeya acutangula*, *Eucalyptus* sp., *Euonymus japonicus*, *Ficus* sp., *F. bengalensis*, *F. elastica*, *F. religiosa*, *F. roxburghii*, *Grevillea robusta*, *gul-i-fanus* (*Lagerstroemia indica*), *Hibiscus* sp., jasmine (*Jasminum pubescens* and *J. sambac*), *jaman* (*Euginia jambolana*), *Mangifera indica*, *Morus alba*, *Murraya exotica*, *Musa sapeientum*, *Nerium odorum*, *N. oleander*, *Poinsettia* sp., *Pongamia glabra*, *Psidium guyava*, *Rosa* spp., *Tecoma* spp., *Vitis vinifera*, *Vitis* sp. and *Zizyphus* spp.

Other workers have found it on the following food-plants also. *Agave americana*, *Aloes* sp., *Camellia thea*, *Coffea arabica*, *Cycas circinalis*, *C. recurvata* and *Morinda tinctoria* [Ramachandran and Ayyar, 1934].

Chief characters

Female scale.—Length 1·72 mm., breadth 1·65 mm., thin, almost circular, slightly convex, yellowish gray, reddish because of the red female which shows through. Exuviae brilliant orange, central.

Female.—Length 0·88-1·20 mm., breadth 0·98-1·36 mm., pyriform and yellow in early adult life, becoming strongly reniform and reddish brown at maturity. Cephalo-thoracic region produced posteriorly forming two convergent lobes which enclose the pygidium.

Pygidium with four pairs of lobes : I pair of lobes largest distinctly separated, disto lateral margins emarginate, distal margin rounded. II pair smaller, otherwise similar to the I pair; some specimens, however, may have the inner margins entire. III pair smaller than II, their inner margins entire, but outer margins distinctly wavy medially. IV pair very poorly developed, triangular.

Incisurae present, filled with serrated plates : I incisura with two slender plates, which are serrated distally. II incisura with two plates, inner plate with its apex serrated and with a median serration laterally and the outer plate bifurcated apically, furcae seratted. III incisura with two stout plates, the inner one deeply bifurcated distally, each branch being serrated along the outer margin and pointed distally, the outer plate deeply serrated on the apex and along its outer margins. IV incisura with three stout plates deeply bifurcated apically, inner branch being slightly, and the outer branch deeply, serrated.

About 12 long, filiform, one-barred, sub-dorsal ducts connected with rows of dorsal pores, disposed of in definite groups ; six pairs of paraphyses or the dorsal club-shaped thickenings are also present.

Ventrum furnished with three heavily sclerotized bodies, one of which has usually a globular inverted V- or U-shaped apophyses. Perivulvar pores absent.

This species resembles San José scale in the general appearance of the scale and in the general shape and colour of the body of the female. It differs from San José scale in : (1) the female becoming red and strongly reniform in shape at period of gestation, (2) the female pygidium having three well-developed and one very poorly developed pair of lobes, (3) the presence of a group of small scleroses on ventrum, and (4) having six pairs of club-shaped paraphyses.

2. *AONIDIELLA CITRINA* (COQ.) : YELLOW SCALE

Ferris, G. F. 1938 : Atlas of the scale insects of North America, *S. 11* : *119*

Distribution

Bannu and D. I. Khan in the N.-W.F. Province and Lyallpur and Nabha in the Punjab.

Food plants

Citrus spp. and *jaman* (*Eugenia jambolana* ; Plate LII, fig. 2). The leaves infested with this scale show many yellow spots or streaks where the chlorphyll has been destroyed ; green fruit too may show such spots. *Jaman* leaves develop red spots.

Chief characters

Female scale.—Length 1·64-1·7 mm., breadth 1·51-1·6 mm., thin, more or less circular ; slightly convex, yellow because of the yellow female which shows through. Exuviae yellow, central or shifted very slightly to one side.

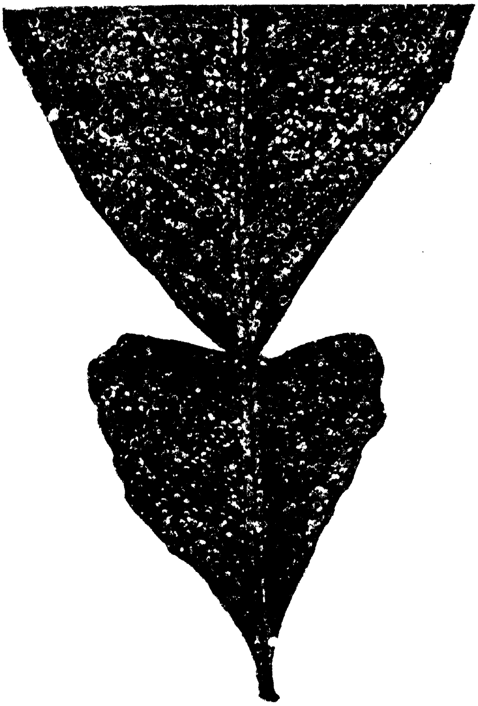


FIG. 1. Citrus leaf infested with *Aonidiella aurantii* (Mask.)

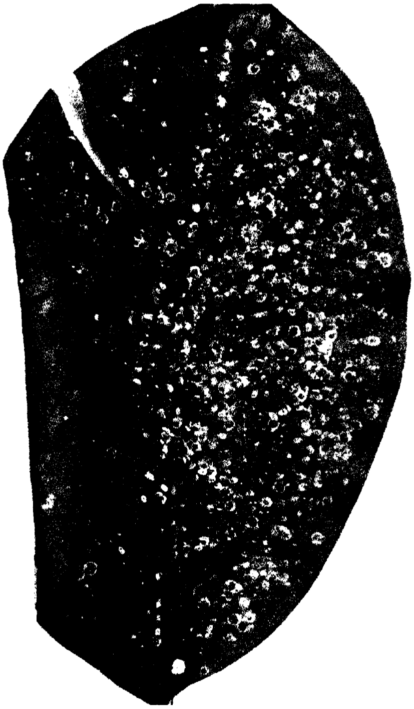


FIG. 2. *Jaman* leaf infested with *Aonidiella citrina* (Coq.)

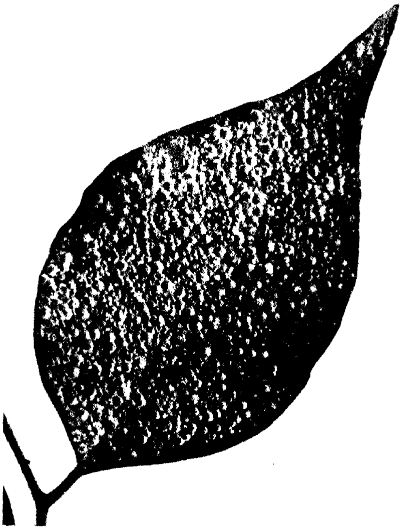
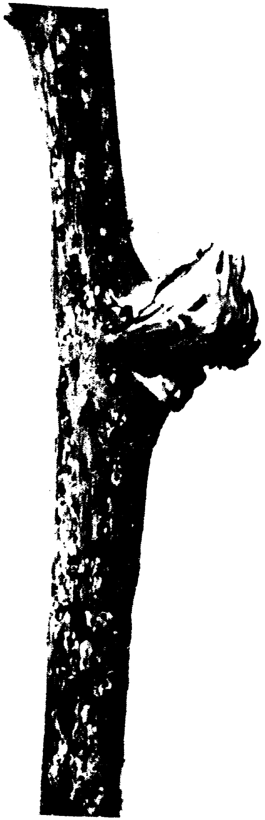


FIG. 3. *Shisham* leaf infested with *Aonidiella orientalis* (Newst.)



1. *Ber* twig infested with *Aonidia zizyphi* sp. n.

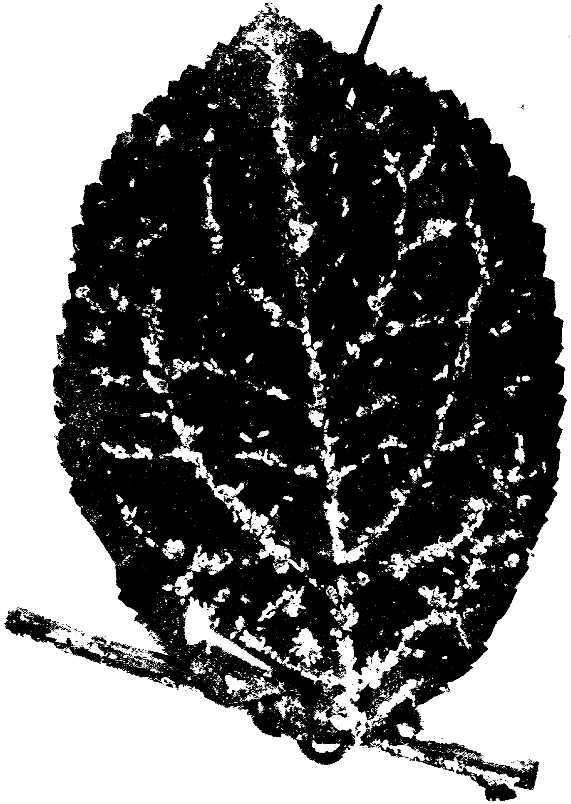


FIG. 2. Peach leaf infested with *Parlatoria oleae* (Colv.)

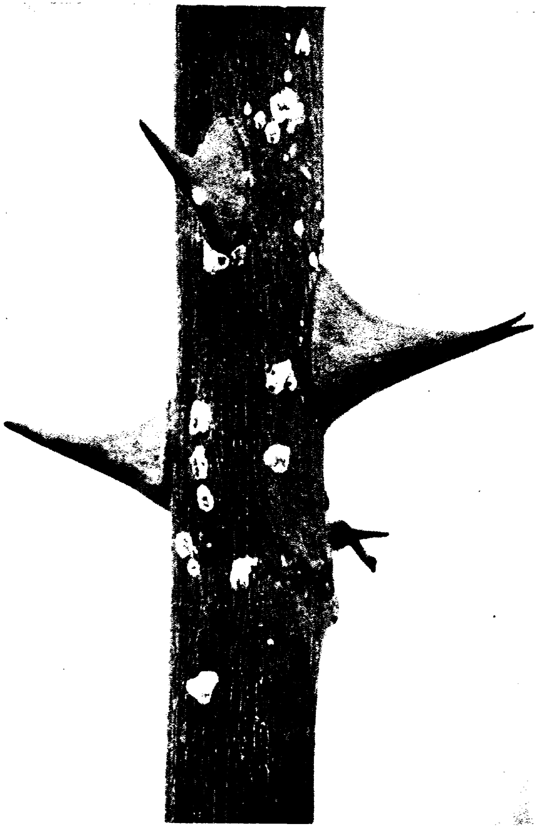


FIG. 3. Rose twig infested with *Parlatoria pseudopyri* Kuw.

Female.—Length 0·97-1·19 mm., breadth 1·00-1·06 mm., pyriform and whitish yellow in early adult life, becoming strongly reniform and yellow at maturity.

Pygidium with four pairs of lobes : I pair of lobes largest, distinctly separated, disto-lateral margins emarginate, distal margins rounded. II pair of lobes smaller, otherwise similar to the I pair. III pair of lobes smaller than II, with lateral margins irregular medially. IV pair of lobes poorly developed, triangular.

Incisurae present, filled with serrated plates : I incisura with two slender plates, which branch profusely distally. II incisura with two plates, outer margins of which are serrated along their distal halves. III incisura with one stout plate, which is deeply bifurcated, each bifurcation being serrated along the distal and lateral margins. IV incisura with three stout plates, each of which is bifurcated apically, each one of the inner bifurcation being slightly serrated and each one of the outer bifurcation being with deeper serrations.

Twelve long, filiform, one-barred, sub-dorsal ducts connected with rows of dorsal pores, disposed of in definite groups ; four pairs of paraphyses also present.

Ventrum furnished with one slender, acute inverted V-shaped sclerotized apophyses [Ferris, 1938]. Perivulvar pores absent.

This insect resembles *A. aurantii* and can be differentiated from San José scale by the characters mentioned under it. It can be differentiated from *A. aurantii* by the presence of only one narrow inverted V-shaped apophysis.

3. *AONIDIELLA ORIENTALIS* (NEWST.) : ORIENTAL YELLOW SCALE

Ferris, G. F. 1938 : Atlas of the scale insects of North America, *S. II* : *120*

Distribution

Punjab.—Ahmadgarh (Bahawalpur State), Bahawalpur, Bilaspur, Darbhanga, Dera Nawab (Bahawalpur State), Dujana, Hoshiarpur, Jind, Jullundur, Lahore, Lyallpur, Montgomery, Muzafargarh, Nahar (Dujana State), Nabha, Pataudi, Sangrur, Sufidan (Jind State), and Texila.

N.-W. F. Province.—Bannu, Nowshera and Thall.

It has also been recorded from Aleppey, Calcutta, Ceylon, Coimbatore, Dhamdha, Guntur, Kistna, Muzaffarpur, Pusa, Rajnagar, and Tinnevelly [Ramachandran and Ayyar, 1934].

Food plants

Acer oblongum, *A. pictum*, *Adhatoda vasica*, *Aegle marmelos*, *Agave* sp., *A. americana*, *A. variegata*, *Ailantus aladulosa*, *Albizzia* sp., *A. lebbek*, *Aloe vera*, *Alpinia nutans*, *Alstonia* sp., *A. scholaris*, *Antigonon leptopus*, *Aristolochia* sp., *Asparagus* sp., *Averrhoa carambola*, *Barleria cristata*, *Bassia latifolia*, *Bauhinia alba*, *B. purpurea*, *B. racemosa*, *B. vahlii*, *B. variegata*, *ber* (*Zizyphus* sp., *Z. jujuba, Z. oenoplia*), *Bignonia radicans, B. vinusta, Bischofia javanica, Bixineae* sp., *Bombax malabaricum, borh* (*Ficus bengalensis*) *Boswellia serrata, Bougain vielae mrs butt, Buxus sempervirens, Broussonetia papyrifera, Bursera serrata, Butea frondosa, Cactus* sp., *Caesalpinia bonducella, Canna indica, Callicarpa macrophylla, Calistemon rigidus, Calotropis procera, Carissa carandas, Cassia auriculata, C. fistula*, castor (*Ricinus communis*), *Cedrela toona, Celastrus paniculata, Celtis* sp., *C. australis, Ceratinia siliqua, chandni* (*Calonyction roxburghii*), *Citrus* spp., *Citharexylum subserratum, Clematis paniculatus, Clerodendron phlomoides, Cordia* sp., *C. myxa, C. obliqua, C. rothii, Crataeva religiosa, Croton tiglium, Cocculus laurifolius, Dalbergia lanceolaria, dharek* (*Melia azadirachta* and *M. composita*), *Diospyros embryopteris, D. montana*, duranta (*Duranta ellisi* & *D. plumieri*), *Ehretia serrata, Eriobotrya japonica* (Japan Medlar), *Erythrina crista galli, Eucalyptus* spp., *Eugenia jambolana, Feronia elephantum, Ficus* sp., *F. elastica, F. infectoria, F palmata, F. retusa, F. roxburghii*, fig. (*F. carica*), *Gmelina arborea, Grewia asiatica, guava* (*Psidium guyava*), *gular* (*Ficus glomerata*), *gul-i-fanus* (*Lager stroemia indica*), *Hiptage madablota, imli* (*Tamarindus indica*), *Inga dulcis, Ipomaea* sp.,' *Jasminum* sp., *Kigelia pinnata, Lonicera chinensis, Maclura aurantiaca, Magnolia grandiflora, Mallotus philippinensis, Mangifera indica, Melia indica, Mimusops elengi, M. Kauki, Mirabilis jalapa, Moringa pterygosperma*, mulberry (*Morus* sp., *M alba* and *M. laevigata*), *Murraya exotica, Musa sapientum, Myrtus communis, Nephelium litchi, Nerium* sp., *Nyctaginacea* sp., *Nyctanthes arbor-tristis*, oak (*Grevillea robusta*), *Ochna squarrosa, Olerodendron inerme, Opuntia* sp., *Oroxlum indicum, Phoenix* sp., *pipal* (*Ficus religiosa*), *Pistacia integerrima, Poinsettia* sp., *Pongamia glabra, Poplar* sp., *Populus alba, Porana paniculata, Pterospermum acerifolium, Punica granatum, Putranjiva roxburghii, Pyrus sinensis, Quisqualis indica, Rhamnus persicus, Rosa* sp., *Salix tetrasperma, sanatha* (*Dodonaea viscosa*), *Sapindus detergens, Sapium sebiferum, Saraca indica, shisham* (*Dalbergia sissoo*) (Plate LII, fig. 3), *Stephegyne parviflora, Sterculia* sp., *S. alata, Swietenia mahagoni, Tabernaemontana coronaria, Tecoma australis, T. stans, T. undulata, Terminalia arjuna, T. belerica, Thunbergia grndiflora, Ulmus* sp., *U. integrifolia, Vitex negundo, Vitis vinifera, Wrightia coccinea, zard kaner* (*Nerium oleander*), *Zizyphus* sp. and *Z. jujuba*.

Other workers have found it on the following plants : *Anacardium occidentale, Atylosia candollei, Bauhinia* sp., *Calotropis* sp., *Carissa* sp., *Chlorxylon swietenia, Cocos nucifera, Dalbergia* sp., *Hygrophylo spinosa, Limonia alata, Manihot glaziovii, Osbeckia* sp., *Panicum* sp., *Polyalthia* sp., *Scheleichera trijuga, Solanum* sp., *Solanum melongena, Tephrosia* sp. [Ramachandran and Ayyar, 1934].

Chief characters

Female scale.—Length 1·47-1·64 mm., breadth 1·23-1·64 mm., thick, more or less circular, slightly convex, yellow to yellowish brown. Exuviae organge-yellow to orange-brown, central or situated slightly to one side.

Female.—Length 1·04-1·15 mm., breadth 1·01-1·18 mm., ovate, yellowish brown in early adult life, becoming roundish and yellowish brown at maturity.

Pygidium with four pairs of lobes and is retracted into prosoma : I pair of lobes stoutest, distinctly separated, disto-lateral margins emarginate. II pair smaller, otherwise similar to the I pair. III pair smaller than II, their outer margins with an almost median emargination. IV pair poorly developed, squat.

Incisurae present and filled with serrated plates : I incisura with two slender plates, which are distally serrated deeply. II incisura with two plates which are serrated distally. III incisura with three plates, each with a deeply serrated apex. IV incisura with three plates, the median arm of each plate being large and produced posteriorly.

Sub-dorsal ducts one-barred, long, filiform, and confined to the submarginal region only where they are disposed of in groups ; six pairs of paraphyses also present.

Ventrum furnished with perivulvar pores which are arranged in five groups.

This species resembles San José scale in the shape of the scale and in general colour and shape of the body of the female. It can be separated from San José scale by the : (1) colour of the scale which is yellow, (2) three pairs of well-developed lobes and one pair of rudimentary lobes (these appear as a point), (3) well-developed and serrated plates the last group of which is club-shaped, and (4) presence of five groups of perivulver pores.

4. *CHRYSOMPHALUS FICUS* ASHMEAD : RED SCALE OF FLORIDA

Newstead, R. 1901 : Mon. Brit. Cocc. *London, I* : *104*

Distribution

Lahore, Lyallpur, Multan, Sargodha and Sialkot. It has also been recorded from Anantpur, Bombay, Calcutta, Cochin, Coimbatore, Maddur, Mysore, Nilgiris, Penukonda, Poona and Malabar [Ramachandran and Ayyar, 1934].

Food plants

Cassia auriculata, *C. occidentalis*, *Citrus* sp., *Feronia elephantum*, *Ficus* sp., and *jaman* (*Eugenia jambolana*). It has also been recorded from the following plants : *Areca catechu*, bamboo, *Cocos nucifera*, *Garcinia indica*, *Mangifera indica*, palms, *Pandanus* sp. *Phoenix* sp., *Rhododendron* sp. and *R. arboreum* [Ramachandran and Ayyar, 1934].

Chief characters

Female scale.—Length 1·97-2 mm., breadth 1·88 mm., circular or moderately so, slightly convex, rather flat, dark reddish brown. Exuviae crimson or dark orange with brown depositions, central or very slightly to one side.

Female.—Length 1·1-1·31 mm., breadth 1·18 mm., ovate and yellowish in early adult life, becoming almost roundish at full maturity. Extremeties of the posterior thoracic margins provided with thoracic tubercles.

Pygidium, broader than long, with three pairs of rather equal lobes : I pair very stout, distinctly separated, their outer margins medially emarginate, and their outer anterior angle with a small seta. II pair similar to the I pair but smaller and with a little deeper emargination, their inner lateral mrgin usually entire, occasionally slightly notched, the small basal setae being located medially on its base. III pair similar to II pair but smaller. Pygidial margin laterad to the III pair of lobes, strongly sclerotized with two equidistant emarginations.

Incisurae present, filled with variously fimbriated plates. I incisura with two plates which are serrated distally. II incisura with two plates which are deeply serrated distally. III incisura with one weaker and two stronger plates, all distally serrated. IV incisura with three stout plates, the anterior and the median arm of each plate being large but slender and produced posteriorly.

Sub-dorsal, one-barred ducts slender, narrow, arising from about the posterior margin of the abdomen, each connected with three dorsal rows of macropores, which are 1-2 in the marginal, 18 in the sub-marginal, and about 22 in the sub-median group. Median group composed of 3-4 stout ducts, which arise from macropores between I and II pair of lobes and extend up to about the middle of pygidium. 1-2 scattered ducts also met with.

Four dorsal scleroses are transversely placed just near the anterior pygidial margin.

Ventrum with five groups of perivulvar pores, median group usually scattered and never making up a definite group, sometime lacking. Microducts few, present along the margin only.

The scale of this species resembles that of San José scale in shape and colour, the females of the two being also identical. It differs from San José scale in the following characters: (1) Four pairs of lobes, three pairs being well developed, and the IV pair being represented by a rounded projection (2) Pygidial plates well developed, and (3) Five groups of perivulvar pores.

5. *QUADRASPIDIOTUS* (*ASPIDIOTUS*) *PERNICIOSUS* (COMST.)

Comstock, J. H. 1881 : Rep. U. S. Dept. Agric., 1880, *p. 304*

Distribution

Punjab.—Simla Hills : Dagshai, Darora, Dhagi, Dhar, Dhari, Kaithu. Kaliana, Kasauli, Khanog, Kiyar, Kotgarh, Kotkhai, Kufri, Loga, Loshta, Marela, Mashobra, Phagu, Rhoga, Sabathu, Subathu Cantt., Salogra, Shainhan, Simla, Solan, Summer Hill, Thanadar.

Simla Hill States: Balsan (Balsan State), Balu (Mandi State), Chaku (Koti State), Gutkar (Mandi State), Jhiri (Mandi State), Jogindar Nagar, Jubbal town (Jubbul State), Kiyar (Koti State), Kuptu (Koti State), Mandi proper, Nagwain (Mandi State), Rajpura (Chamba State), Sundar Nagar (Suket State), Tandu (Mandi State), Tatal (Madhan State).

Kulu Valley : Ani, Aramgarh, Arsu, Bahu, Bandrol, Bajaura, Banuri, Chowai, Deem, Dhaogi, Dhara, Dhobi, Haripur, Jibi, Jagat Sukh, Katrain, Kulu, Manali, Naggar, Nigali, Ohalpur, Palampur, Pati, Raison, Sharar, Trimli, Urthu.

Gurdaspur district : Dalhousie, Banikhet.

Murree Tehsil : Lower Rewat.

Kashmir Valley : Achhabal, Baramula, Harwan, Islamabad, Khanabal, Srinagar.

United Provinces.—Saharanpur, Chaubattia (Almorah district), Mussoori (Dehra Dun district).

N.-W. F. Province —Peshawar.

Hazara district : Abbotabad, Boi (Pattan side), Kakul, Malikpur, Oghi (Agror Valley).

Kurrum Valley : Agra, Alizia, Bilyamin, Gharbina, Kirman, Lukmankhel, Malana, Parachinar, Shalozan, Shingak, Shublan, Sultan, Ziran.

South Waziristan Agency.—Wana.

Food plants

Akik (*Canna indica*), alder (*kosh : Alnus nepalennis* and *A. nitida*), almond (*Prunus amygdalus*), wild almond (*Prunus* sp.), *alubukhara* (*Prunus divaricata*), apple (*Pyrus malus*), crab apple (*Pyrus* sp.), apricot (*Prunus armeniaca*), wild apricot (*Prunus* sp.), *arghanjo* (Parachinar wild plants : *Pyrus* sp. and *Prunus* sp.), *bhang* (*Cannabis sativa*), chestnut (*Castanea sativa*), cherry (*Cerasus vulgaris*), wild cherry (*Prunus* sp.), hawthorn (*Crataegus* sp.), lilac (*mahan : Ulmus* sp.), oak (*Quercus dilatata*), peach (*Prunus persica*), wild peach (*Prunus* sp.), pear (*Pyrus communis*), wild pear (*shegal, batangi*, etc. *P. pashia*), plum (*Prunus cummunis*), *cherai* (Parachinar local plum : *Prunus* sp.), Japan plum (*P. japonica*), wild plum (*Prunus* sp.), quince (*Cydonia vulgaris*), *siris* (*Albizzia lebbek*), walnut (*Juglans regia*), willow (*Salix* sp.) ; rose (*Rosa* sp.) and Persian rose (*Rosa* sp.).

The attacked plant becomes grayish in colour and appears scurfy and scabby. The infested fruit develops prominent scarlet circular areas at the point of infestation.

Chief characters

Female scale.—Length 1·31-1·64 mm., breadth 1·15-1·31 mm., almost circular, slightly convex, grayish. Exuviae yellowish brown with dark gray mid-dorsal cover, almost circular.

Female.—Length 0·91-1·48 mm., breadth 0·75-1·23 mm., ovate or almost circular, yellowish.

Pygidium acute, with three pairs of lobes [Rahman, 1940]. I Pair of lobes large, strongly sclerotized, deeply notched about midway on the outer margins. II pair of lobes smaller, strongly sclerotized, conspicuously notched on the outer margin. III pair of lobes rudimentary, represented by a triangular projection.

Incisurae furnished with plates. I incisura with a pair of small setaceous plate. II incisura with one setaceous and one narrow plate which is finally serrated dorso-laterally. III incisura with three narrow plates, serrated dorso-laterally. Three low, broad plates laterad of the III lobe.

Dermal sclerotic areas well defined along the margin and sub-median areas.

Sub-dorsal, one-barred, tubular ducts short, narrow, about 24 in number, connected with dorsal circular pores arranged in four definite groups, as well as scattered at random.

Ventrum without perivulvar pores, ventral ducts very few, narrow and short. Pygidial ventral inter-incisural scleroses (densariae) are well developed.

6. *ASPIDIOTUS DESTRUCTOR* SIGN.,: BOURBON ASPIDIOTUS

Ferris, G. F. 1938 : Atlas of scale insects of North America, *S. II* : *191*

Distribution

Amritsar, Jind, Lahore, Lyallpur, Multan, Muzaffargarh, Pataudi, Sufidan and Sangrur (Jind State) in the Punjab and Bannu and Dera Ismail Khan in the N.-W. F. Province. It has also been recorded from Anantpur, Bombay, Bengal, Ceylon, Coimbatore, Gujrat, Kumbalenguna, Laccadives, Malabar, Mundanthurai, Mysore, Nilgiris, Pusa, South Canara, Tinnevelly and Wynad [Ramachandran and Ayyar, 1934].

Food plants

Banana (*Musa sapientum*), *Bauhinia* sp., *Jasminum* sp., mango (*Mangifera indica*) and *Psidium guyava*. It has also been recorded on *Alocasia* sp., *Camellia thea*, *Calotropis* sp., *Carissa* sp., *Cassia* sp., *Citrus* sp., *Cocos nucifera*, *Eugenia* sp., *E. jambolana*, *Gelonium lanceolatum*, *Loranthus* sp., *Maesa indica*, *Musa paradisiaca*, *Piper nigrum*, *Phoenix* sp., *P. dactylifera*, *Psychotria* sp., *Ricinus communis*, rubber, *Solanum melongena*, *Tamarindus indica* [Ramachandran and Ayyar, 1934].

Chief characters

Female scale.—Length 0·74 mm., breadth 0·65 mm., very thin, circular, very slightly convex, whitish yellow. Exuviae pale yellow, central.

Female.—Length 0·59-0·65 mm., breadth 0·52 mm., ovate, yellowish with pygidium deep yellow.

Pygidium with three pairs of sub-equal lobes. I pair of lobes prominent, well separated, their margins distally emarginate. II pair of lobes emarginate on outer margins only. III pair of lobes similar to II pair but smaller.

Incisurae furnished with long prominent plates. I incisura with two stout plates. II incisura with two plates. III incisura with three plates, one of which is lacinate. There are six to seven plates beyond the III pair of lobes also.

One-barred dorsal ducts moderately long and narrow, and arranged in four groups.

Ventrum with four to five groups of perivulvar pores.

The adult female of this species resembles the adult female of San José scale in colouration and shape and in the number of lobes on the pygidium. It differs from it as follows : (1) Scale very thin and parchment-like, (2) Three pairs of well-developed but narrow lobes, (3) About 15 fimbriated plates along each pygidial half, and (4) Perivulvar pores present.

7. *AONIDIA ZIZYPHI* SP. N.

Puparium of female 1·1-1·2 mm. long, 0·9-1·1 mm. broad, whitish gray, almost circular, convex dorsally. Exuviae yellow to dark orange, slightly towards the margin.

The first skin 0·28-0·39 mm. long, 0·26-0·37 mm. broad, orange-yellow ; antennae five jointed, a little longer than the space between them, last segment a little longer than the other four taken together. I pair of lobes of the pygidium widely separated, tridentate apically and prominently notched on their outer margins, II pair of lobes tooth-like, III pair of lobes inconspicuous.

The second skin 0·88-1·2 mm. long, 0·8-1·1 mm. broad, almost circular and covers the female completely ; I pair of lobes of the pygidium prominent, slightly dentate apically and prominently notched on their outer margins ; II pair of lobes triangular ; III pair of lobes small but easily made out ; pygidial margin beyond the II pair of lobes provided with eight glandular spines, fimbriated plates absent. Dorsal ducts very small, confined to the margins only.

Adult female almost circular, yellowish to reddish brown, enclosed in a puparium, 0·65 mm. long and 0·73 mm. broad, with no lateral projections. Prosoma with no lateral ducts, abdominal segments with gland spines and lateral gland ducts. Antennal segment situated just behind the frontal margin, is bidentate, and has a long bristle (Plate LI, fig. 4) ; spiracles as in other species, but the I pair with three parastigmatic pores, which are arranged in the form of a triangle.

Pygidium without perivulvar pores; I pair of lobes fairly well developed, basally convergent and apically divergent, disto-lateral margin emarginate, II pair of lobes small, triangular and without emargination. Pygidial margin laterad of II pair of lobes, distinctly irregular, fringed with eight setae as shown in the figure. Pectinae or plates are entirely wanting. Anal orifice small, quite near the median lobes. Dorsal pores marginal, sub-dorsal ducts very few, small, slender, and thread-like.

Distribution

Bannu, Ghoriwala, Nar Sabat Shah (Bannu), Nartahal Ram (Bannu) and Nurar Road.

Food plant

Zizyphus jujuba (Plate LIII, fig. 1).

Holotypes.—Female puparia from Bannu (Nartahal Ram) on *Zizyphus jujuba*, in the Entomological Laboratory, Punjab Agricultural College, Lyallpur.

This species resembles *Aonidia shastae* (Coleman) [Ferris, 1938] from which it is separated by the absence of fimbriated plates on the pygidial margin.

The scale of this species resembles San José scale in its form and colour, specially when II stage puparium is exposed. The female differs from that of San José scale in the : (1) absence of serrated plates, (2) dorsal ducts being very short and distributed along the margins only, and (3) presence of two pairs of lobes on the pygidium.

8. *PARLATORIA OLEAE* (COLV.) : OLIVE PARLATORIA

Ferris, G. F. 1937 : Atlas of the scale insects of North America, *S. I* : *97*

Distribution

Punjab.—Ahmadgarh (Bahawalpur State), Aleo (Nabha State), Arazi (Kahuta Tehsil), Bahawalpur, Balao (Theog State), Bansragali (Murree), Barian (Murree), Bhagali (Banjar), Bhanuri, Bilaspur, Chabiana (Bahawalpur State)

Charhan (Murree), Chattar (Murree), Dera Nawab (Bahawalpur State), Dharampur (Simla), Dharamsala, Dhami, Dujana, Ghoragali (Murree), Gurdaspur, Jind, Jullundur, Junga (Keonthal State), Kalka, Katrain, Kherpur (Bahawalpur), Kiyar (Koti State), Kumarsain, Loharu, Luan (Kumarsain), Lyallpur, Madhan, Malerkotla, Mashobra (Simla), Masot (Murree), Mukerian, Mul Bhaji (Bhaji State), Nabha, Narkanda (Kumarsain State), Palampur, Parola (Theog State), Pataudi, Raison, Rawalpindi, Rewat (Murree), Sabathu (Simla), Saidpur, Sambli (Murree), Sanawar, Shali (Theog State), Simla, Sowl, Topa (Murree).

N.-W. F. Province.—Bannu, Boorki (Parachinar), Dadar (Hazara), Darsamand, Ghoriwala (Bannu), Hangu tehsil, Jandota (S. Waziristan), Kasar Fatehkhel, Lookmankhel, Lora village, Lundidak, Mirjamal, Mistakhel, Paharpur, Parachinar, Shablan (Parachinar), Shingok, Wana and Ziran (Parachinar). It has also been recorded from Central India, Madras and Pusa [Ramachandran and Ayyar, 1934].

Food plants

Crab apple (*Pyrus* sp.), apple (*Pyrus malus*), apricot (*Prunus armeniaca*), arghanju (Parachinar wild plant : *Prunus* sp.), *Caragana ambigua*, *dharek* (*Melia composita*), *gula-i-fanus* (*Lagerstroemia* sp.), *hari* (*Prunus* sp.), *Jasminum sambac*, *J. pubescens*, *kaint* (*Pyrus* sp), *kaner* (*Nerium odorum* and *N. oleander*), *kosh* (*Alnus nepalensis* and *A. nitida*), *loghuna* (Parachinar wild plant), loquat (*Eriobotrya japonica*), *Mangifera indica*, *Melia azadirachta*, *nim* (*Melia indica*), olive (*Olea europaea*), peach (*Prunus persica*) (Plate LIII, fig. 2), wild pear (*Pyrus pashia*), pear (*Pyrus communis*), persimmon (*Diospyros kaki*), plum (*Prunus communis*), *taklu* and *wang* (Parachinar local plants) and *Zizyphus jujuba*. It has also been recorded as *P. calianthina* B. & L. on *Michelia* sp. [Ramachandran and Ayyar, 1934].

Chief characters

Female scale.—Length 1·23-1·64 mm., breadth 1·06-1·31 mm. ovate or slightly round, convex, whitish gray to pale gray. Exuviae yellowish brown, apical.

Female.—Length 0·69-0·85 mm., breadth 0·57-0·65 mm., ovate, whitish yellow to yellowish brown, excepting pygidial centre which is pinkish-yellow.

Pygidium with four pairs of lobes : I pair of lobes well developed and distinctly separated, outer margins alone deeply notched. II and III pairs slightly smaller than the I pair, otherwise similar to it. IV pair very small, ill-defined, triangular.

Incisurae furnished with broad plates : I incisura with a pair of very short, narrow plates, the distal margins of which are poorly bifurcated. II incisura with two slightly stronger, narrower plates with at least three distal furcae. III incisura with three similar plates, but broader than the preceding ones. IV incisura with 4 plates, sub-equal, irregularly furcated on the distal margins. Three plates beyond IV incisura, slightly different in depth of dentation : four to five plates succeeding these are bluntly dentate and tuberculate.

Sub-dorsal, two-barred ducts numerous, broader and smaller. Margina ducts broader and smaller and opening in very heavily sclerotized semi-lunar oral scleroses. The rest comparatively smaller, distributed along lateral margins of the abdominal segments only.

Ventrum with three groups of glandular tubercles on thorax : five groups of perivulvar pores disposed of as shown in the figure. Micro-ducts few, small, disposed of along the margins of the abdominal region.

This species resembles the San José scale in the colour of the scale which is surrounded by a reddish inflamed area. It differs from the San José scale as follows : (1) Four pairs of lobes (three well-developed, 4th ill-defined), (2) About 18 plates on each pygidial half, (3) Five groups of perivulvar pores, and (4) Sub-dorsal ducts two-barred and numerous.

9. *PARLATORIA PSEUDOPYRI* KUWANA

Takahashi, R. 1938 : Proc. Roy. Ent. Soc. London, (B) vii 12 : *272*

Distribution

Punjab.—Amritsar, Bhawalpur, Bannu, Bahakkar, Dera Nawab (Bahawalpur State), Dujana, Gobindgarh, Jind, Kalka, Kherpur (Bahawalpur State), Lahore, Loharu, Lyallpur, Malerkotla, Muzaffargarh, Multan, Pataudi, Rawalpindi, Sangrur (Jind State) and Texila.

N.-W. F. Province.—Bannu, Darsamand, D. I. Khan (Musazai and Bilot) Serai Narang, Shabqaddar and Wana.

Food plants

Almond (*Prunus amygdalus*), apple (*Pyrus malus*), *bael* (*Aegle marmelos*), *Bauhinia* sp., *B. alba*, *B. purpurea*, *B. vahlii*, *B. variegata*, *Boswellia serrata*, *Buxus sempervirens*, *Buddleia mapagascamensis*, *Calotropis procera*, *chandni* (*Calonyction roxburghii*), *Cestrum nocturnum*, *Celastrus paniculata*, *Croton tiglium*, *Cryptostegia grandiflora*, *Cocculus laurifolius*, *dharek* (*Melia* sp. and *M. azadirachta*), *Ebenacea* sp., *Eugenia jambolana*, *Euonymus japonicus*, *Flacourtia sapida*, *gul-i-fanus* (*Lagerstroemia indica*), *Haematoxylon campachianum*, *Hamelia patens*, *Hibiscus mutabilis*, *H. rosa-sinensis*, *H. tiliaceus*, *Hypericum cernum*, *Jagan booti* (Bahawalpur local plant), *junga* (A Parachinar shrub), jasmine (*Jasminum arborescens*, *J. humile*, *J. pubescens* and *J. sambac*), *kaner* (red and white flowers:—*Nerium odorum* and *N. oleander*), *Lonicera chinensis*, *lasura* (*Cordia myxa*, *C. obliqua* and *C. rothii*), loquat (*Eriobotrya japonica*), mango (*Mangifera indica*), *Myrtus communis*, *Nandia domestica*, *Nephelium litchi*, *nim* (*Melia indica*), *Nyctanthes arbor-tristis*, *Ochna squarrosa*, *phalsa* (*Grewia asiatica*), *pipal* (*Ficus religiosa*), *Prunus divaricata*, *Prunus persica*, *Prunus communis*, *Pyrus sinensis*, *Rhamnus persicus*, *Rosa* spp. (Plate LIII, fig. 3) *Rubus fruticosus*, *Spirae corymbosa*, *Tabernaemontana coronaria*, *Urena lobota*, *Vitis* sp. *Woodfordia floribunda* and *Zizyphus* sp.

It is recorded for the first time from India. We believe it to be present in all places where rose is grown. At Lyallpur there was very heavy infestation on rose in 1937-38. An unidentified chalcid parasite and a coccinellid (*Thea bisoctonotata* Mul.) checked it very successfully at Lyallpur.

Chief characters

Female scale.—Length 1·64-1·8 mm., breadth 1·15-1·45 mm., oval, convex whitish gray to dark gray. Exuviae pale yellow and apical.

Female.—Length 0·82-1·00 mm., breadth 0·71-0·82 mm., pyriform translucent, yellowish pale, pygidium being deeper yellow, Pygidium with four pairs of lobes : I pair of lobes stoutest, well separated, deeply notched on both sides. II pair smaller and narrower than I, deeply notched only on the outer margin. III pair similar to II pair, but smaller. IV pair rudimentary, without notches.

Incisurae furnished with broad serrated plates : I incisura with two narrow spine-like plates which are distally serrated. II incisura similar to the I incisura. III incisura with one seta-like and two serrated plates. IV incisura with two strong and broad, distally truncate plates and one narrow, setaceous plate. About 16 broad and strong plates beyond, all of them more or less similar in form but differing in size and degree of dentation.

Sub-dorsal two-barred ducts small, scattered, quite numerous in the sub-marginal region of the pygidium. Marginal ducts broader, opening in heavily sclerotized semi-lunar scleroses : sub-marginal ducts narrower and smaller.

Ventrum with two groups of glandular tubercles on the thoracic region and one such group near the perivulvar pores. Four groups of perivulvar pores are present. Micro-ducts very few or obsolete.

This species closely resembles *P. olea* (Colv.). For characters by which it resembles San José scale as well as those by which it differs from it see under *P. olea* (Colv.).

10. *LAPAZIA PESHAWARENSIS* SP. N.

Puparium of female 0·82-1·18 mm. long, 0·36-0·51 mm. broad, elongate, whitish gray to yellowish gray, convex, excepting apical third which is flattened. Larval pellicles terminal, reddish brown, covering at least half of the scale.

The first skin 0·29-0·38 mm. long, 0·16-0·19 mm. broad, yellowish red ; antennae six-jointed, proximal joint longer and setaceous ; I pair of lobes of the pygidium squat, widely separated ; II pair of lobes vestigeal ; pygidial margin furnished with two prominent spurs.

The second skin 0·59-0·74 mm. long, 0·25-0·41 mm. broad. I pair of lobes of the pygidium wider than long, notched at the apex, widely separated, II pairs of lobes smaller, triangular. Margin of the pygidium with four spur-like prominences ; each spur with a setaceous plate below it and a fifth plate inner to the I lobe of the pygidium. Six to eight marginal two-barred ducts present.

Adult female 0·59-0·64 mm. long, 0·21-0·33 mm. broad, elongate, fusiform, translucent white or slightly yellowish, pygidium always deeper yellow. Prosoma provided with a few lateral ducts throughout ; abdominal segments clear ; gland spines absent, glandular ducts present along the lateral margins. Antennae situated midway between the front and the mouthparts with a blunt tooth above and two stout setae below (Plate LI, fig. 8). Mouthparts normal, spiracles without parastigmatic pores.

Pygidium with two lobes : I pair well defined, broader than long, their lateral margins straight, and apical margins rounded and slightly notched at end. II pair smaller, dentate. Margin of pygidium with four spur-like prominences, each bearing an oval pore ; plates reduced, simple and spine-like, each with a micro-duct at its base.

I incisura with two setaceous plates. II incisura with one plate, one plate at the base of each glandular spur and two on abdominal segments. Two-barred sub-dorsal ducts somewhat irregularly distributed on metathoracic and abdominal segments, except on pygidium, where they are arranged roughly in marginal, sub-marginal and sub-median groups. Marginal ducts comparatively broader, sub-marginal and sub-median ducts varying generally from two to three and always arranged in a definite pattern. Their exact distribution and arrangement is shown in the figure. Anal opening just near the anterior pygidial margin. Vaginal opening almost central. Ventrum with very fragile micro-ducts which are not easily discernable. Perivulvar pores absent.

Distribution

Bannu, Charsadda, Darsamand, D. I. Khan, Malana, Mardan, Parachinar, Paharpur, South Waziristan (Sarwaki, Tanai and Wana), Taru Jabba and Thall.

Food plants

Plum (*Prunus communis*) and peach (*Prunus persica*).

Holotype.—Female puparia from Taru Jabba (Peshawar) on peaches, in the Entomological Laboratory, Punjab Agricultural College, Lyallpur.

This species was placed in the genus *Pinnaspis* by Dr Takahashi, but the authors differ from him because this genus includes those species which have strongly zygotic median lobes, and five groups of perivulvar pores : *Lapazia peshawarensis* does not possess these characters. Ferris [1937] described only one species of this genus and *Lapazia peshawarensis* does not resemble it.

The leaves attacked by this species develop grayish patches, tender shoots begin to dry up from their tips downwards.

It produces red spots on fruits, closely resembling those caused by San José scale. It differs from San José scale in the following features : (1) Scale elongate, (2) Adult female fusiform, (3) Two pairs of pygidial lobes, (4) Spur-like pygidial prominences, (5) Plates reduced and spine-like and (6) Dorsal ducts two-barred.

SUMMARY

The Imperial Council of Agricultural Research, New Delhi, sanctioned a scheme in April 1937 for three years to carry out a survey of the Punjab and the N.-W. F. Province, in order to find out the distribution and food plants of San José scale. This survey brought to light nine other Coccidae of economic importance which closely resemble San José scale either in their morphology or in symptoms of their attack, and as such are usually mistaken for it. These Coccids are as follows :—*Aonidiella aurantii* (Mask.), *Aonidiella citrina* (Coq.), *Aonidiella orientalis* (Newst.), *Chrysomphalus ficus* Ashm., *Aspidiotus destructor* Sign., *Aonidia zizyphi* n. sp., *Parlatoria oleae* (Colv.), *Parlatora pseudopyri* Kuw. and *Lapazia peshawarensis* n. sp. Their distribution, food plants and the chief distinguishing characters together with the characters by which they can be separated from San José scale are discussed. Two

species, namely *Aonidia zizyphi* n. sp. and *Lapazia peshawarensis* n. sp., are new to science and they are described here for the first time.

ACKNOWLEDGEMENTS

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REFERENCES

Ayyar, T. V. R. (1929). *Bull. Agric. Res. Inst. Pusa*, **197**

Borkhsenius, N. (1935). *Plant Prot.* **6**, 127-33 (In Russian, translation kindly supplied by Sir Guy A. K. Marshall)

Comstock, J. H. (1881). *Rep. U. S. Dept. Agric. 1880*, pp. 270-349

Ferris, G. F. (1937). *Atlas of the scale insects of North America, Series I*

——————(1938). *Atlas of the scale insects of North America, Series II*

Newstead, R.(1901). *Mon. Brit. Cocc.* **1**

——————(1903). *Mon. Brit. Cocc.* **2**

Rahman, Khan A. (1940,1). *Indan Farm.* **1**, 387-90

—————— (1940,2). *Final Report on the Combined Entomological Scheme, Punjab and N.-W. F. Province*

Ramachandran, S. and Ayyar, T. V. R. (1934). *Misc. Bull. Imp. Coun. Agric. Res.* **4**

Takahashi, R. (1938). *Proc. R. Ent. Soc. London (B)* **7**, 271-2

ABSTRACT

Scope and Use of Experiment Station Record. EDITORIAL ARTICLE: *Experiment Station Record* 84, No. 4, April 1941

EXPERIMENT Station Record published by the United States Department of Agriculture is, as the name suggests, a record of experiment station accomplishments. The station material occupies half the 138 pages in each issue. A substantial portion is occupied by the research contributions from the Federal Department of Agriculture. The remaining space is available for abstracts from non-station and non-Department sources. In order to conserve space, station annual reports are not abstracted, as they are essentially progress reports, but all findings are enumerated. At present the major research developments in agriculture and home economics are being placed on record for the United States and Canada and other parts of the British Empire to the extent that this research is widely applicable to conditions in the United States of America. Special attention is also being given to contributions from Central and South America.

Apart from the Station and Department publications and a considerable number of exchanges, the principal channel through which material becomes available for abstracting is the Department Library. The Library receives 3,871 periodicals, according to the list published in 1936 (*Miscellaneous Publication* 245 *of the Department of Agriculture.*) Another publication of value to users of the *Record* is Miscellaneous Publication 337, *Abbreviations Used in the Department of Agriculture for Titles of Publications* (1939). This gives addresses and a key for single words which is helpful especially in identifying recent publications. These two publications will obviate many inquiries to the Office of Experiment Stations.

Copies of original publications from which abstracts are made cannot be sent as spare copies are not available. Requests for copies of Departmental publications should be made to the Office of Information. The publications of the State experiment stations are distributed by the individual institutions. Books and periodicals must be purchased from the publishers, but reprints of articles are sometimes obtainable from their authors or their institutions.

Probably the most striking development in documentation aids in recent years has been the application of photography to the making of copies. Through the operation of Bibliofilm Service by the American Documentation Institute in cooperation with the Department Library, photographic reproductions may now be obtained for purposes of research for virtually any article abstracted in the *Record*. These reproductions are available in two forms, photo-prints, which can be read without magnification, and microfilm furnished at much lower cost but requiring a magnifier or projecting apparatus. Order blanks and details for this service can be obtained from the Bibliofilm Service, care of the Library, United States Department of Agriculture, Washington, D. C. It is believed that for certain types of articles, such as short papers appearing in voluminous or relatively inaccessible proceedings, this service has many advantages.

The classification of abstracts in the *Record* follows a plan of many years' standing. Cross references are not employed, and users are advised to read related sections, e.g. the soil conservationist should read not only the section on soil but also the sections of Agricultural Meteorology, Agricultural Botany, Field Crops, Forestry, Agricultural Engineering, Agricultural Economics and even Rural Sociology. Ultimately the subject indexes are available regardless of sectional lines, but these indexes should not be too narrowly used.

The best method of using the *Record* as a guide to the accomplishments of the past half century is by means of the combined subject indexes. There are six of them and additions are made every five years. The second of the group covering vols. 13—25 is no longer available, but the others can be obtained free of charge by libraries and for institutional use. The Office of Experiment Stations is always glad to help in completing files for both the general indexes and the individual volumes. (Abstract)

REVIEWS

Handbook of economic entomology for South India. By T. V. Ramakrishna Ayyar. (Superintendent, Government Press, Madras, 1940), pp. 528, Rs. 4-12-0

THIS is a timely book which will be of the greatest use to Indian entomologists. The first book on the insects of Madras, *Some South Indian Insects*, was published in 1914 by T. B. Fletcher, the Government Entomologist, Madras, during 1912-14, and later on the Imperial Entomologist, Pusa. Since then there has been a growing demand specially from students of agriculture and educated farmers for a handy, up-to-date volume on South Indian insects especially those of economic importance. Mr. Ayyar's work represents an attempt to meet such a demand. It will be specially useful to students of agricultural colleges because the plan of the book and the matter included in it form an elaboration of the college lectures on entomology which were given by the author to the students of the Madras Agricultural College for over 20 years. The book is divided into two parts ; (*i*) the general part of six chapters briefly giving some fundamental ideas of insects and their various activities, and (*ii*) a special part including general discussions on insect pests, some of the control measures against them, and a brief annotated summary of the important insects of economic importance so far recorded from South India on different crops. There are useful appendices on classification and control given at the end of the book. Credit is due to the Superintendent, Government Press, Madras, for the neat printing and the fine get-up of this useful volume. Mr. Ayyar deserves the congratulations of all agricultural workers for this very useful handbook. (S. C. R.)

The Grasslands of the Argentine and Patagonia. By William Davies (*Bulletin No.* **30**, *Herbage Publication Series, Imperial Bureau of Pastures and Forage Crops, Aberystwyth, G. B.*, 1940), pp. 46, 2*s*. 9*d*.

IN this *Bulletin* is published the report by Mr William Davies, Senior Grassland Investigator, Welsh Plant Breeding Station, Aberystwyth, of his tour of South American Grasslands. The object of Mr Davies' tour has been to study the present condition, and the potential and immediate possibilities of improvement of the grasslands of the Argentine Republic. For this purpose he travelled across the Republic in a south to north direction covering a vast distance in a short time. In all, 23 grass farms (stations) were visited ; and the visit was sufficient to give him an idea of the existing conditions. Even though it was not possible for him to survey the country in greater detail, the tour has furnished much information of importance.

The report of Mr Davies gives a short description of the climatic and geographical conditions of the Republic, which, because of its situation in a north to south direction, includes a variety of climates. The southern one-third of the Republic, which covers a greater portion of Patagonia, and which is situated in the cold temperate region and is arid for a greater part of the year, is mostly under sheep' ranching. The Argentine proper, in which is situated the La Plata Basin, has a mediterranean climate, and as such is of considerable agricultural and pastoral importance. Both cattle and sheep are maintained, but cattle are more important than sheep. In the northern portion, having a sub-tropical climate, chiefly cattle are reared.

Argentine Republic is the leading lucerne-growing country of the world and had over 13,000,000 acres under it in 1933-34. The peak production was during 1920-21, when there were over 20,000,000 acres under lucerne. According to Mr Davies, even this does not appear to be the limit to which its cultivation may be extended. It is pointed out that the Province of Buenos Aires and adjacent ones possess potentially the richest grazing land in the world, and it is significantly remarked, 'Were this land to be properly developed, it has the potentiality of vast output as a reservoir of human and animal food'. But Mr Davies states that if such a development takes place, it wolud set up a serious competition with the agriculture and livestock industry of Great Britain, the British Dominions and Colonies, particularly Australia and New Zealand. At present the livestock industry in Argentine is restricted to cattle feeding, but the dairy side, which is still undeveloped, has not materially competed in the past with Australia and New Zealand. It is pointed out that the Province of Buenos Aires if properly planned could be organized into an intensive dairying and fat lamb producing area. With the soil and climate possessed by Argentine, the potentialities for organizing dairying industry are so great that it would require very little, if any, outlay beyond the mere application of the technique of grassland improvement practised in Great Britain and New Zealand.

The remaining part of the report is devoted to a general consideration of the eight zones into which the grasslands of the Argentine Republic have been divided. The possibilities of improvement and methods to be adopted with respect to each zone are given. In the latter part of the report is published detailed notes on the 23 stations visited by Mr. Davies.

A large number of photographs, a map, a glossary of common plant names and figures relating to stock and crops have considerably enhanced the value of the report. (L. S. S. K.)

PLANT QUARANTINE NOTIFICATIONS

FOREIGN

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

1. *Summaries of plant quarantine import restrictions*
    - (*i*) Plant Quarantine Import Restrictions of the Kingdom of Iraq (Mesopotamia)
    - (*ii*) Plant Quarantine and Import Restrictions of the Republic of Uraguay.
2. (*i*) Service and Regulatory Announcements—April-June 1940.
    - (*ii*) Service and Regulatory Announcements—July-September 1940.
    - (*iii*) Index to Service and Regulatory Announcements —1939.
3. *Other announcements*
    - (*i*) Government of Burma, Department of Agriculture and Forests Notification No. 377, dated the 16th December 1940.
    - (*ii*) Government of Burma, Department of Agriculture and Forests Notification No. 13 (corrigendum), dated the 15th January 1941.
    - (*iii*) Government of Burma, Department of Agriculture and Forests Notification No. 56, dated the 28th February 1941.
    - (*iv*) Government of Burma, Department of Agriculture and Forests Notification No. 89, dated the 24th April 1941.
    - (*v*) North Borneo—
        - (*i*) Agricultural Pests (Prohibited Plant) Rules, 1940.
        - (*ii*) Notification No. 105—Schedule of charges in respect of inspections and fumigations.
        - (*iii*) Notification No. 106—Giant Snail declared agricultural pest.

INDIA

Notification No. F./43-32(6)/40-A. issued by the Government of India in the Department of Education, Health and Lands

IN this Department Notification No. F.-43-32/40-A., dated the 16th January 1941, for the word ‘ fruits ’ the words ‘ plant products ’ shall be substituted.

GIPD—3 S—189 IC of AR—25-10-41—750.

ORIGINAL ARTICLES

COLCHICINE-INDUCED POLYPLOIDY IN CROP PLANTS

I. GRAM (*CICER ARIETINUM* L.)

BY

S. RAMANUJAM

AND

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(Received for publication on 26 May 1941)

(With Plates LIV-LVIII)

POLYPLOIDY has been the subject of intensive research for over a quarter of a century among plant-breeders and geneticists. This was due mainly to the fact that polyploidy was found to be of widespread occurrence in nature—more than 50 per cent of the angiosperm species being polyploids —and also to the fact that polyploid plants turned up fairly frequently in experimental cultures of various workers. The mode of origin of these polyploids and their importance in evolution are now fairly well known. The realization of the far-reaching effects of polyploidy in producing new and superior types of plants to the existing ones naturally led to experiments on the artificial production of polyploids.

The earliest discovery in the direction of obtaining polyploids artificially was made by Winkler in 1916 when he attempted to produce graft hybrids in *Solanum*. This method was subsequently developed by Jorgensen [1928] and later employed for various purposes by Lindstrom and Koos [1931], Sansome [1931] and several others. Greenleaf [1938] obtained polyploids from callus shoots of *Nicotiana* and its species hybrids by employing hetero-auxin to induce callus formation. The range of applicability of this method is still not fully worked out. Of the other methods, that of temperature treatment employed by Randolph [1932] proved the most effective. Working with maize he reported the production of about 5 per cent polyploids in his experiments. This method was later used by Dorsey [1936] and Peto [1936] who, however, reported varying successes. Occasional polyploids were also obtained in various other ways : by X-rays [Ichijima, 1934], by bacteria [Kostoff and Kendall, 1932], and by centrifuging [Kostoff, 1937 ; 1938,1], etc.

By far the easiest and the most successful method for inducing polyploidy was discovered recently by Blakeslee and Avery [1937], and Nebel and Ruttle [1938]. These authors working independently showed that colchicine, an alkaloid occurring in the seed and corm of *Colchicum autumnale*, when applied in weak concentrations in water to growing parts of plants produced polyploids. Since this discovery was announced, experiments were undertaken in all parts of the world to test the efficacy of this alkaloid for producing polyploids and the results obtained have in the main fulfilled expectations. A comprehensive review of work done in this connection is given by Fyfe [1939] and Dermen [1940]. Another chemical that has since been reported to produce similar effects on plants is acenaphthene [Kostoff, 1938,2 ; Navashin, 1938]. The success obtained with this chemical is not as universal as with colchicine [Nebel, 1938 ; Blakeslee, 1939] although it is reported to have certain advantages over the latter [Levan, 1940].

In India work on the production of polyploids by the use of colchicine was taken up at the Imperial Agricultural Research Institute and a number of crop plants subjected to treatment with the chemical have been under study. A preliminary account of striking results obtained with chilli (*Capsicum annuum* L.) was published by Pal and Ramanujam [1939]. Amin [1940] in Surat and Richharia and Persai [1940] in Nagpur have also reported the production of polyploids in cotton and sesamum respectively by the use of colchicine. In this paper an account of work done and results obtained with colchicine treatment of gram is given.

MATERIALS AND METHODS

Seeds of gram variety I P 25 were soaked in water for 24 hours and then placed on moist filter paper for germination. Just at the stage when the radicles began to emerge, the seeds were immersed in aqueous solutions of colchicine of different concentrations for different periods of time. The concentrations employed were 0·25 per cent, 0·5 per cent and 1·0 per cent and the periods of immersion included ½ hour, 2 hours, 6 hours and 24 hours. Ten seeds were used for each treatment, the total number of treatments being twelve. After treatment, the seeds were washed in distilled water and placed on damp filter paper in Petri dishes for further germination. After about a week, the seedlings were planted out separately in pots filled with sterilized soil. For every treatment, seeds soaked in distilled water for corresponding periods were sown as controls.

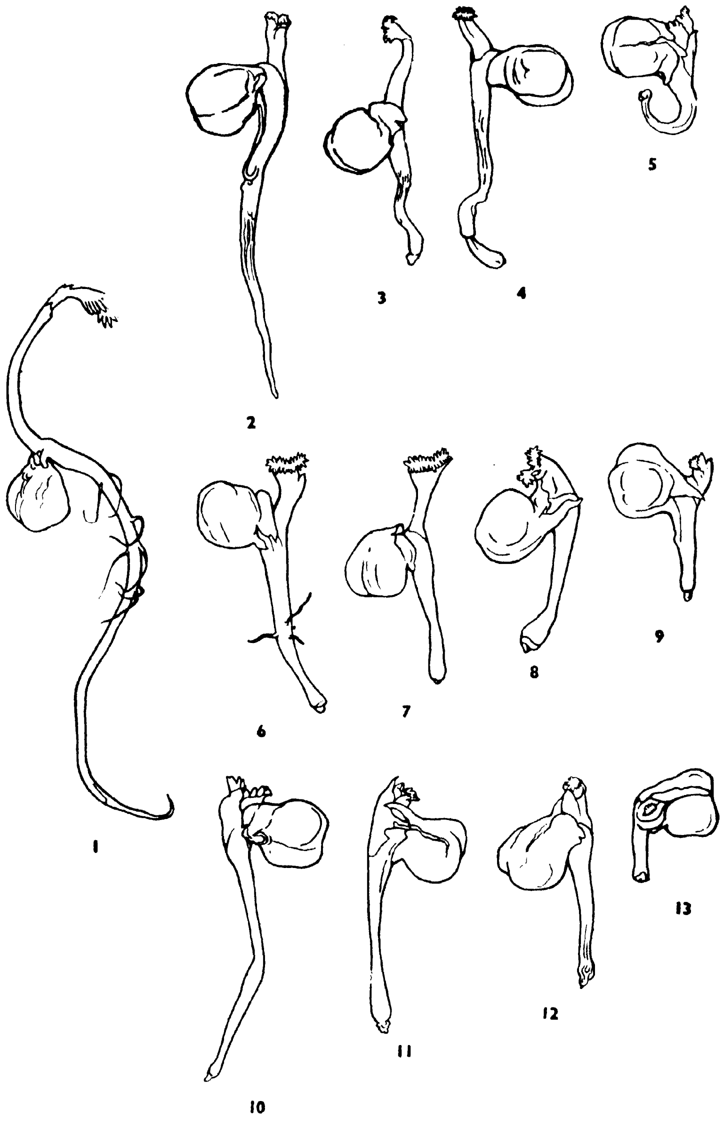
Observations on the growth and flowering of colchicine-treated plants (C_1 generation) and their progenies (C_2 generation) were taken together with controls. The size of stoma guard cells, pollen size and sterility were examined in each case for preliminary detection of induced polyploidy. These observations were supplemented by the study of mitoses in root tips and meioses in pollen mother cells in as many plants as possible. Root tips were fixed in Navashin's fluid and sections stained with iodine-gentian-violet. Meioses in pollen-mother-cells were studied exclusively in acetocarmine smears made permanent by McClintock's schedule [1929]. Drawings were made with the aid of a camera lucida at bench level using a 2 mm. apochromatic objective and 15 × and 20 × compensating oculars.

MORPHOLOGY OF COLCHICINE-TREATED PLANTS

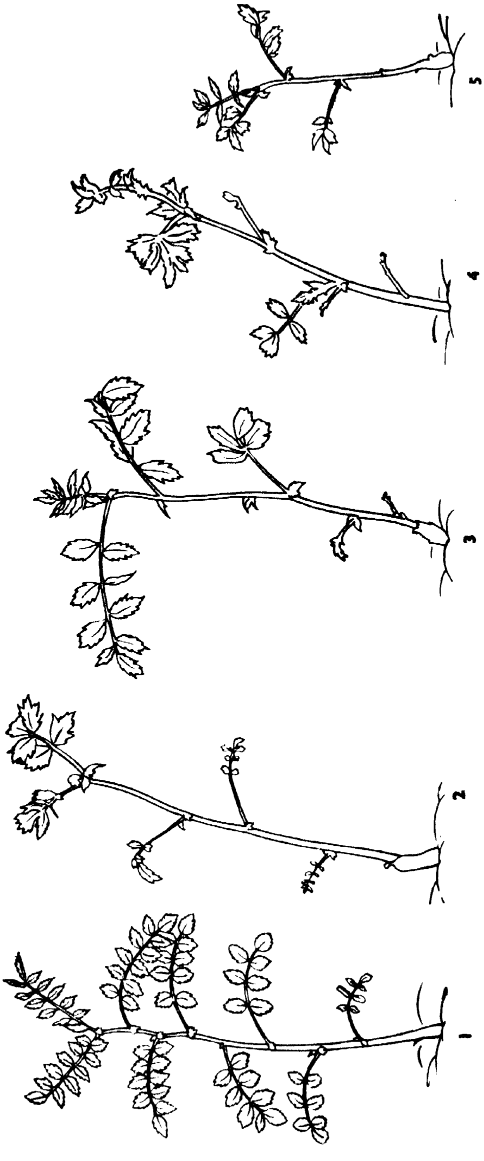
C_1 generation

The immediate effect of treatment of the seeds was a swelling of the radicles and the plumules and a retardation of their growth compared to the untreated controls. Although all the seeds in any one treatment were not affected to the same extent, the abnormalities induced by treatment appeared to vary with the concentration of colchicine and the duration of treatment. Increased concentrations and longer durations caused a more pronounced swelling and a greater delay in the growth of the plumules and radicles. In some of the heavier treatments the growth of the plumule was completely checked and the radicle began to dry up. Germinating seeds six days after

GERMINATING SEEDS SIX DAYS AFTER TREATMENT



1. Control; 2–5. Treated with 0·25 per cent colchicine for $\frac{1}{2}$, 2, 6 and 24 hours respectively; 6–9. Treated with 0·5 per cent colchicine for $\frac{1}{2}$, 2, 6 and 24 hours respectively; 10–13. Treated with 1 per cent colchicine for $\frac{1}{2}$, 2, 6 and 24 hours respectively



1. Control ; 2–5. Abnormal seedlings due to colchicine treatment

treatment are shown in Plate LIV, figs. 1-13. It will be seen from figs. 5, 9 and 13 that longer durations of treatment produced characteristically stunted and swollen seedlings. Only a very small percentage of such seedlings developed into mature plants. Table I gives the number of plants in the different treatments that grew to maturity and the proportion of polyploids in each treatment.

The total number of plants obtained from treatment with 1·0 per cent solution was considerably less than that from weaker concentrations. Similarly, the total number of plants from longer durations of treatment was less than that from shorter durations. From the data available it would appear that treatment of seeds with 0·25 per cent solution for ½ hour is the best from the points of view of survival of plants and induction of polyploids.

The treated seedlings, after transplantation in pots, continued to grow very slowly compared to the controls ; several of them died in various stages of growth, presumably due to an intolerance to the chemical. Many of the surviving seedlings showed characteristic abnormalities in growth in the early stages, such as curling and twisting of the stem and leaves and a roughening of their surface. The apical bud in some cases stopped growth following a swelling of the apex of the stem and one of the cotyledonary shoots took its place. Plate LV, figs. 1-5 show a few of the abnormal seedlings compared to a control. Later on, the abnormal seedlings grew more or less normally, though slowly, compared to the controls, producing thicker stems, broader and darker leaflets than the latter. Of the 26 plants derived from the treatments, only 13 developed these characteristics of slow growth with thicker stems and darker and broader leaves, the other 13 developing normally like the control plants. The 13 gigas plants came into flower four to five days later than the others. The size of flowers in the gigas plants was bigger than that in the controls. An examination of pollen size and size of stoma guard cells of these plants compared to the controls showed them to be polyploids, the sizes of pollen and stoma guard cells of the polyploids being bigger than those in control plants. Pollen sterility in the polyploid plants varied from 40 to 80 per cent, while that in the control plants did not amount to more than 10 per cent in any case. A cytological examination of meioses in pollen-mother-cells of these 13 plants showed that all of them were tetraploids. In one plant, however, a branch was noticed with considerably broader leaflets and larger stomata, which may have been an octoploid, but this dried up without producing flowers.

C_2 generation

Seeds from individual branches of the 13 tetraploid plants were collected separately and grown in pots during 1939-40 together with controls. The resulting plants were studied carefully with regard to their morphological characters, such as height of plant, number of main branches, number of leaves on the tallest branch, number of leaflets per leaf, length and breadth of leaflets and the standard petal, size of stoma guard cells and pollen size and sterility. The individual plants were also examined for chromosome numbers. The nature of progenies obtained from the different plants tabulated branchwise is given in Table II and the data regarding morphological characters in Table III.

TABLE I

Results of colchicine treatment of gram, I P 25

(1938-39)

Concentration of colchicine ::→	0·25 per cent					0·5 per cent					1·0 per cent					Control		
Duration of treatment ::::→	No. of seeds treated	No. of plants obtained	No. of polyploids	Per cent Survival	Per cent polyploids	No. of seeds treated	No. of plants obtained	No. of polyploids	Per cent survival	Per cent polyploids	No. of seeds treated	No. of plants obtained	No. of polyploids	Per cent survival	Per cent polyploids	No. of seeds	No. of plants obtained	Per cent. survival
1/2 hour . . .	10	10	6	100	60	10	4	1	40	10	10	3	1	30	10	10	10	100
2 hours	10	4	1	40	10	10	2	1	20	10	10	...	...	...	...	10	10	100
6 hours	10	3	3	30	30	10	...	...	...	...	10	...	...	...	...	10	10	100
24 hours . . .	10	...	...	...	...	10	...	...	...	...	10	...	...	...	...	10	10	100

TABLE II

Progenies of colchicine-treated plants, C_2 generation
(Seeds sown branchwise)
(1939-40)

Plant No. in 1938-39	Branch No.	No. of seeds sown	No. of plants obtained	No. of diploids $2n=16$	No. of polyploids $2n=32$	Remarks
2	Did not set seed					
5	5—1	5	2	2	..	
	5—2	1	1	..	1	
	5—3	1	1	..	1	
	5—4	1	1	..	1	
	5—5	2	1	..	1	
	5—6	1	..	..	..	Mixoploid
		11	6	2	4	
7	7—1	1	1	..	1	
	7—2	1	1	..	1	
	7—3	1	1	..	1	
	7—4	2	2	2	..	
	7—5	2	2	..	2	Mixoploid
		7	7	2	5	
8	8—1	5	4	4	..	Mixoploid ?
9	9—1	2	2	..	2	Polyploid
10	10—1	6	6	6	..	
	10—2	8	4	4	..	
	10—3	1	1	..	1	
	10—4	1	1	1	..	
	10—5	3	3	3	..	
	10—6	4	4	4	..	
	10—7	4	4	4	..	
	10—8	1	1	1	..	
	10—9	7	5	5	..	Mixoploid
		35	29	28	1	

TABLE II—*contd*

Plant No. in 1938-39	Branch No.	No. of seeds sown.	No. of plants obtained	No. of diploids $2n=16$	No. of polyploids $2n=32$	Remarks
13	13—1	5	5	5	..	
	13—2	1	1	1	..	Mixoploid ?
		6	6	6	..	
23	23—1	1	1	..	1	
	23—2	1	..	..	..	Polyploid
		2	1	..	1	
31	31—1	2	2	..	2	
	31—2	..	..	..	..	
	31—3	2	1	..	1	Polyploid
		4	3	..	3	
44	Did not set seed					
61	61—1	2	1	1	..	
	61—2	1	..	..	..	
	61—3	1	1	..	1	Mixoploid
		4	2	1	1	
62	62—1	9	9	9	..	
	62—2	1	1	..	1	
	62—3	1	1	..	1	Mixoploid
		11	11	9	2	
63	63—1	1	1	..	1	Polyploid

It is seen from Table II that in many cases seeds from different branches have given rise to different types of plants with regard to chromosome numbers. Plants 5, 7, 10, 61 and 62 have given rise to both diploids and tetraploids, thereby showing that the original plants obtained directly from treatment contained mixed 2 n and 4 n tissue. Plants 9, 23, 31 and 63 gave rise to only a few seeds, all of which produced tetraploids. In these cases it is likely that the whole plants were of 4 n tissue. Plants 8 and 13, however, gave rise t only diploids. These plants were originally very sterile and produced only

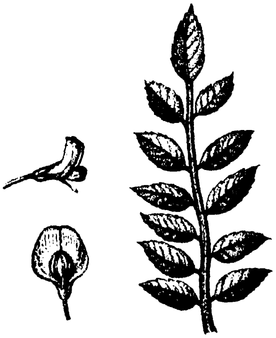


FIG. 1. Flower and leaf of a diploid plant

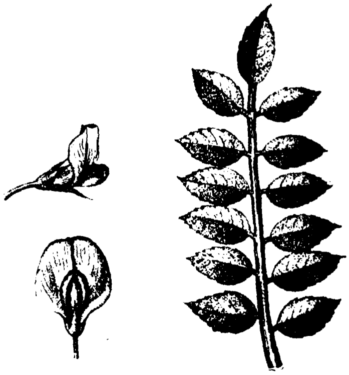


FIG. 2. Flower and leaf of a tetraploid plant

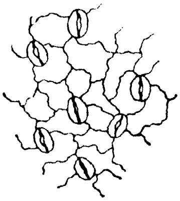


FIG. 3. Stomata on the leaf of a diploid plant

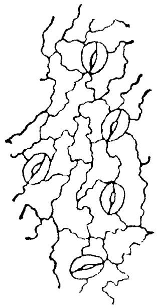


FIG. 4. Stomata on the leaf of a tetraploid plant

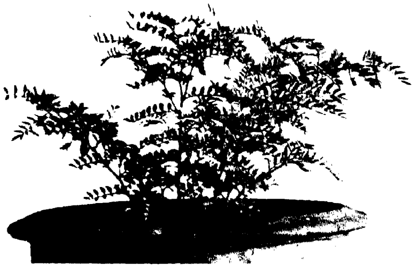


FIG. 1. A diploid plant

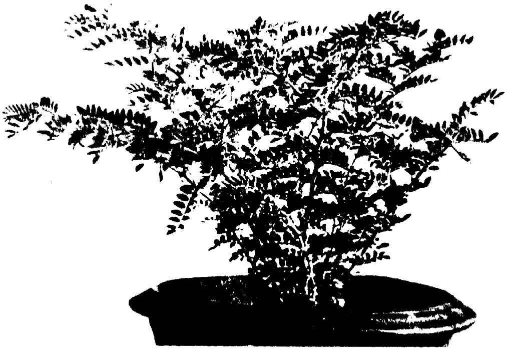


FIG. 2. A tetraploid plant

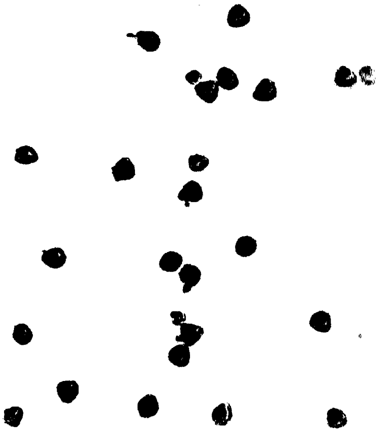


FIG. 3. Pollen from a diploid plant

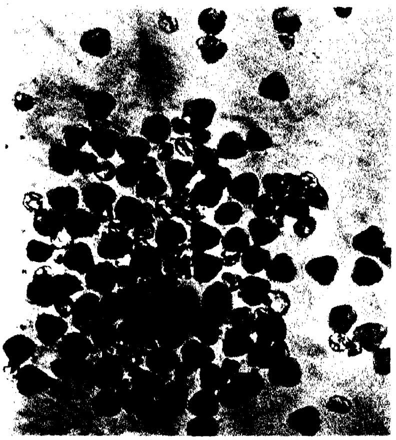


FIG. 4. Pollen from a tetraploid plant

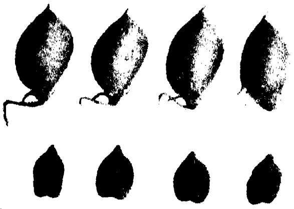


FIG. 5. Pods and seeds of a diploid plant

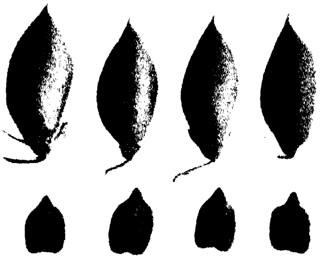


FIG. 6. Pods and seeds of a tetraploid plant

few branches that set seed. It is probable that in these cases also the plants were mixoploids but that the polyploid branches did not produce seeds to give polyploid progeny. These results clearly show that when seeds are treated with colchicine, mixed 4 *n* and 2 *n* sectors develop on the plants arising from treatment, which causes abnormalities owing to differential growth rates of these tissues and that pure tetraploids are recovered only on growing a further generation.

An examination of Table III brings out some of the morphological changes induced in the gram plants as a result of a quantitative change in chromosome number from a diploid to a tetraploid condition. The cell size in the tetraploid is increased as shown by the stoma guard cells and the pollen. The sizes of the leaflets and the flowers are also increased. The increased size of these plant parts are shown in Plate LVI, figs. 1-4 and Plate LVII, figs. 3 and 4. The pod size and the seed size are also increased in the tetraploid compared to the diploid as shown in Plate LVII, figs. 5 and 6. The height of plants in the tetraploids does not show any significant variation from the diploids although in regard to the number of main branches the diploid has more branches than the tetraploid. These results agree in general with those obtained with other artificially induced polyploids [Kostoff, 1938, 3]. Plate LVII, figs. 1 and 2 are photographs of a diploid and a tetraploid, but the difference in height shown by them is not a general feature as is evidenced by the measurements obtained on a large number of plants. The tetraploid pollen is only partially fertile compared to the diploid, the sterility in the former varying from 40 to 80 per cent, while that in the latter is not more than 10 per cent in any case. Our knowledge of quantitative variations induced by polyploidy and their effects as studied in artificially induced polyploids are as yet meagre as pointed out by Stebbins [1940]. The physiological effects of these quantitative changes on the plants themselves yet remain to be fully investigated and this study was handicapped up to now by the lack of a sure method of obtaining polyploids in large numbers. It is here that the discovery of Blakeslee and others of producing polyploids at will holds great promise for the future.

It must be mentioned that the range of variability of the morphological characters studied is more in tetraploids than in diploids. This may in part be due to secondary effects of the treatment. It is worth while growing the tetraploids for a number of years and in different localities for determination of their reactions to different environments and to natural selection. During the year 1940-41, 62 tetraploid plants were raised and their pollen sterility determined compared to the diploids. The following are the data obtained for the years 1939-40 and 1940-41 :—

Per cent sterility . . .	0-35	36-45	46-55	5665	66-75	76-85
No. of tetraploids (1939-40) .	..	3	7	6	3	2
No. of tetraploids (1940-41) .	..	25	17	10	4	6

It would appear from the data that there is a shift in the number of plants towards greater fertility in the C_3 generation. This indication is significant in the light of the observations of Muntsing [1936] that natural selection over a long period of time may lead to increased fertility among auto-polyploids.

TABLE III

Diploids and tetraploids compared with regard to some of the plant characters

(1939.40)

Serial No.	Plant characters	Tetraploids			Diploids			Difference between means (M.D.)	S. E. of difference	$\frac{\text{M. D.}}{\text{S. E.}}$ of diff.	Remarks
		No. of plants recorded	Mean ± standard error	standard deviation	No. of plants recorded	Mean ± standard error	Standard deviation				
1	Pollen size (mean diameter).	21	43·750µ to 46·875µ		55	34·375µ to 37·500µ					The mean diameter of tetraploids is 1¼ times that of diploids, which is equal to twice the volume.
2	Pollen sterility (range)	,,	40—80 per cent		,,	Nil to 5 or 10 per cent					Tetra. > Di.
3	Number of main branches	,,	8·3809 ±0·6813	3·122	,,	10·8 ± 0·4745	3·5192	2·4191	0·8303	2·91	Di. > Tetra.
4	Number of leaves on the tallest branch	,,	25·85 ±0·3734	1·711	,,	24·54 ±0·2376	1·7619	1·31	0·4426	2·96	Tetra > Di.
5	Height of plant in cm.	,,	30·26 ±0·7176	3·29	,,	29·49 ±0·4138	3·0686	0·77	0·8284	0·93	Difference not significant
6	Number of leaflets per leaf	,,	14·03 ±0·1356	0·6221	,,	13·74 ±0·0305	0·2261	0·29	0·1390	2·09	Tetra. > Di.
7	Length of leaflet in cm.	,,	1·027 ±0·02512	0·1151	,,	0·92 ±0·0105	0·0781	0·1070	0·02723	3·93	Tetra. > Di.
8	Breadth of leaflets in cm.	,,	0·6452 ±0·01396	0·06403	,,	0·4483 ±0·00453	0·03362	0·1969	0·01468	13·41	Tetra. > Di.
9	Length of the guard cell of stomata in µ	,,	42·68 ±0·2217	1·0159	,,	31·38 ±0·07359	0·5458	11·3	0·2336	48·37	Tetra. > Di.
10	Breadth of the guard cell of stomata in µ	,,	30·97 ±0·1257	0·574	,,	24·21 ±0·09665	0·7168	6·76	0·1586	42·62	Tetra. > Di.
11	Maximum length of flower standard in cm.	19	1·106 ±0·1442	0·0628	30	0·911 ±0·007694	0·04214	0·195	0·01634	11·93	Tetra. > Di.
12	Maximum breadth of flower standard in cm.	,,	0·9194 ±0·01442	0·0628	,,	0·6946 ±0·007176	0·03931	0·2248	0·01611	13·95	Tetra. > Di.
13	Number of days from sowing till flowering	21	65·3	...	55	62·4	...	...	...	...	

CYTOLOGY

The chief criteria employed for a preliminary detection of polyploidy in the colchicine-treated plants were based on the increased size of pollen and stoma guard cells. Cytological studies invariably supported the results of these observations.

The chromosome number of *C. arietinum* has been determined by various workers. Dombrowsky-Sludsky [1927], Rao [1929], and Dixit [1932] reported its somatic number as 14. The last-named author, however, reported $2n=16$ as the number in a certain large-seeded Kabuli variety which he called *C. Kabulicum*. The authors working with many varieties studied by Dixit obtained $2n=16$ chromosomes in each case ; in no case was the number $2n=14$ met with. Avdulov [1937], Iyengar [1939], and Richharia and Kalamkar [1938] have also reported the chromosome number of the species as $2n=16$. Polyploid species of *Cicer* are unknown, nor have naturally occurring or artificially produced polyploids of *C. arietinum* been reported.

In the present investigation both mitosis and meiosis of the diploid and the artificially produced tetraploid plants of I P 25 were studied. In the root tips of the diploid, 16 chromosomes (Plate LVIII, fig. 1) were clearly counted in several cells while in the tetraploids 32 chromosomes (Plate LVIII, fig. 2) were clearly seen. In pollen meiosis in the diploid, eight bivalents were found at diakinesis and mataphase I (Plate LVIII, fig. 3) and these underwent regular separation at anaphase I (Plate LVIII, fig. 4). At metaphase II, 8 chromosomes in each nucleus were noticed (Plate LVIII, fig. 5). The second division was also regular leading to the formation of normal tetrads. Pollen sterility in the diploids varied from 0 to 10 per cent. In the tetraploids varying numbers of quadrivalents and bivalents were formed at diakinesis and metaphase I, the total number of chromosomes in each cell being 32. An examination of 34 cells at diakinesis and metaphase I in which the chromosomes were clearly spaced out gave the following distribution of quadrivalents :—

No. of quadrivalents . . .	0	1	2	3	4	5	6	7	8	
Number of cells	0	0	0	2	1	8	7	12	4	= 34

The maximum number of quadrivalents was noticed in 4 out of 34 cases, while seven quadrivalents per cell appeared to be of frequent occurrence. Plate LVIII, figs. 6-8 show different numbers and shapes of quadrivalents occurring in three cells. Anaphase I was fairly regular in many cells and the chromosomes were distributed equally, i.e. 16 and 16 to the two poles. The following gives the frequencies of distribution of chromosomes to the two poles at anaphase I.

Distribution of chromosomes	16+16	17+15	18+14
Number of cells	16	6	2

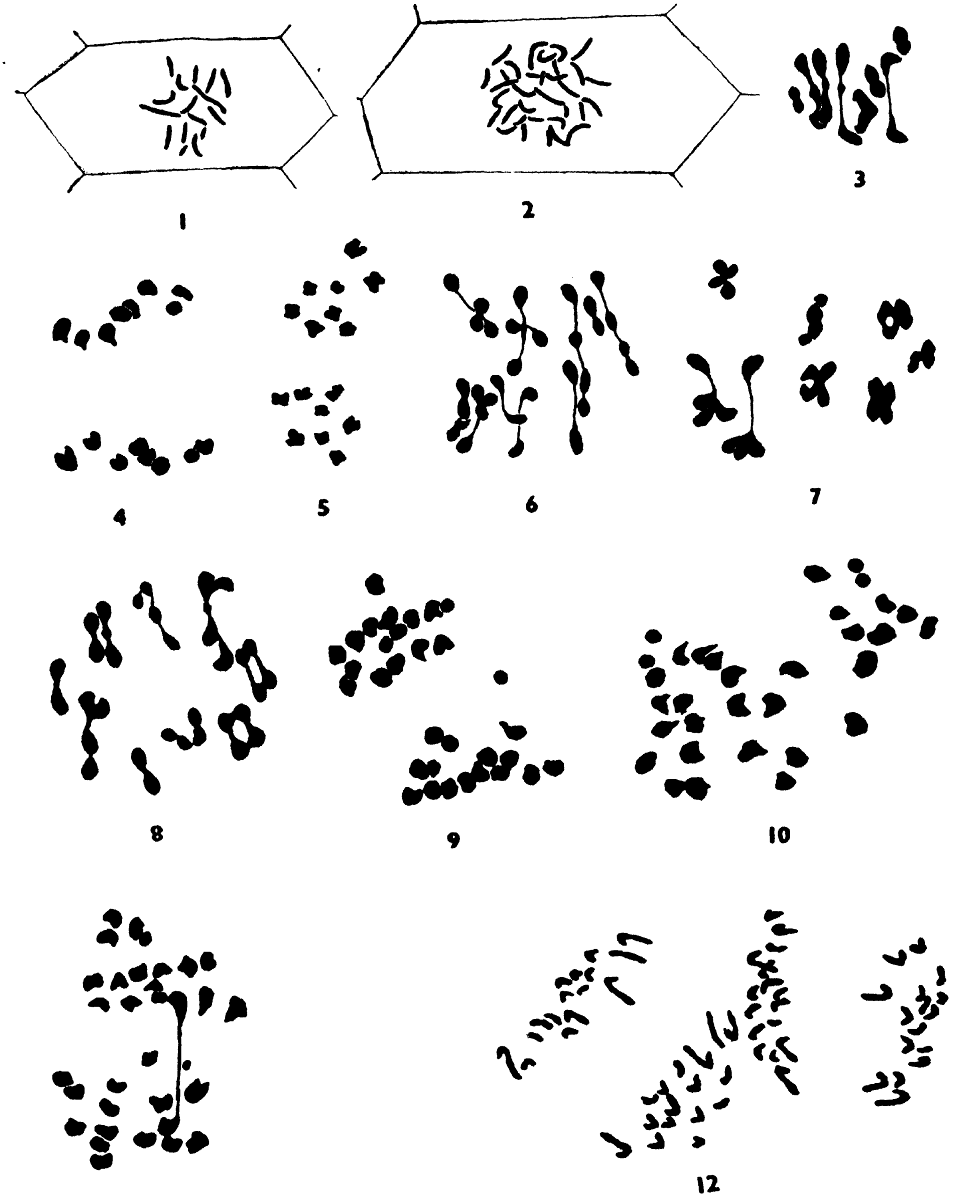
Plate LVIII, figs. 9 and 10 represent cells with equal and unequal distribution of chromosomes to the poles at anaphase I. Occasionally, in some cells one chromosome was seen to lag at anaphase I and get excluded from the daughter nuclei or was seen to divide into half chromosomes and move to opposite poles. In one plant with about 80 per cent pollen sterility, a chromatin bridge with a fragment (Plate LVIII, fig. 11) was noticed at anaphase I in a few cells. This obviously has resulted from the occurrence of an inverted segment in one of the chromosomes. No such inversion bridges were noticed in the diploid material examined. The second division in the pollen-mother-cells of tetraploids was also fairly regular with 16 chromosomes going to each of the four poles (Plate LVIII, fig. 12). Irregularities at division II, such as the presence of straying chromosomes, etc. were rather rare. In spite of the fairly regular divisions the sterility of pollen in the different tetraploids varied from 40 to 80 per cent. It is noteworthy that progenies of tetraploid plants consisted of only tetraploids ; this is presumably owing to the functioning of only $2n$ gametes to the exclusion of others.

DISCUSSION

It is now well known that the effect of colchicine in doubling the chromosome number of flowering plants is of rather general application, although different species or even related species may require different treatments for successful results. This knowledge has opened out new opportunities to the breeder who is interested in the production of new and improved types of economic plants. The doubling of chromosomes can be induced in fertile species or in sterile species hybrids ; in the former case partially sterile auto-polyploids are obtained and in the latter more or less fertile allo-polyploids are produced. Allo-polyploids are known to have played an important part in evolution as has been demonstrated not only by the numerous and well-known instances of artificial species, such as *Primula kewensis* [Newton and Pellow, 1929], *Nicotiana digluta* [Clausen and Goodspeed, 1925] *Aegilotricum* [Katayama, 1935] *Raphanobrassica* [Karpechenko, 1927] and others but also by the experimental synthesis of natural species like *Galeopsis Tetrahit* [Muntzing, 1932]. Further evidence of their importance in evolution is provided by those of our cultivated plants whose polyploid origin has been worked out, as in the case of wheat [Aase, 1930 ; 1935], cotton [Skovsted, 1934], tobacco [Kostoff, 1936], etc. The importance of allo-polyploidy in evolution lies in the fact that it induces far-reaching changes in sterile species hybrids ; allo-polyploidy is known to have changed a self-sterile species into a self-fertile form, a dioecious into a hermaphrodite race and an annual into a perennial. It is also known to have induced resistance to diseases, pests, frost and drought conditions. As a result of these distinctive features and an increased rate of mutation in them, allo-polyploids are better suited for the production of altogether new forms. While the study of species hybrids, therefore, occupied an important place in the programme of the breeder, its scope was limited by the lack of a sure method of doubling the chromosome number. The discovery of this new method has given an impetus to this line of work and already several artificial polyploids by the use of colchicine have been obtained. Fertile amphidiploids from sterile species hybrids in *Nicotiana* [Warmke and Blakeslee, 1939 ; Kostoff, 1938,4 ; Smith, 1939], in cotton [Beasley, 1940 ; Harland, 1940 ; Kasparayan, 1940], and in wheat [Zhebrak, 1939,1 ; 1939,2], have been obtained which promise results of economic value. Further studies in this direction are full of possibilities for the future of plant breeding.

Auto-polyploidy, on the other hand, has given rise to a great diversity of opinion with regard to its role in evolution. Auto-polyploids usually do not show differences in morphological character from the diploids except for certain size variations induced by a quantitative change in their chromosome

PLATE LVI



1-2. Somatic chromosomes in the root tips of a diploid and a tetraploid gram respectively ; 3-5. Pollen meiosis in the diploid showing metaphase I, anaphase I, and metaphase II respectively ; 6-8. Pollen meiosis in the tetraploid showing different configurations of quadrivalents ; 9-10. Pollen meiosis in the tetraploid showing late anaphase I with equal and unequal distributions, respectively, of chromosomes to the poles ; 11. Pollen meiosis in the tetraploid showing anaphase I with a chromatin bridge and a fragment ; 12. Pollen meiosis in the tetraploid showing anaphase II

number. They, however, exhibit certain physiological differences such as the slower rate of development, later time of blooming, and an inability to cross with the diploids which give them in many cases a different geographical or ecological distribution. How far are these changes induced by auto-polyploidy effective in evolution ? The question is discussed at length by Muntzing [1936] who by an analysis of intra- and interspecific chromosome forms and experimental auto-polyploids adduces arguments in favour of auto-polyploidy being a factor in evolution. Although Jorgensen [1928], Blakeslee [1921], and Babcock [1934] agree with Muntzing in considering that auto-polyploidy has played a part in evolution, other workers like Afzelius [1924], Clausen [1926], and Navashin [1927] think that new polyploid species cannot possibly arise only ' by multiplication of the same genome ', i.e. auto-polyploidy. Stebbins [1940] discussing the same question states, ' Furthermore, due to the fact that polyploid species are more infertile than their diploid prototypes, an auto-tetraploid is unlikely to maintain its purity unless it is completely isolated not only from its diploid progenitor, but from its polyploid relations as well. Would such a completely isolated race, which would have to become highly inbred, and in which the visible mutation rate is greatly reduced, be likely to give rise to a new line of evolution ? I doubt it.' Muntzing [1936] considering the question of difference in fertility between polyploid chromosome races and experimental auto-polyploids—the former are more fertile than the latter—states that ' this difference is explicable by the fact that chromosome races in contradistinction to the experimental polyploids have been subject to natural selection. They (the polyploid chromosome races) represent the successful survivors from a large material. It is also possible that secondary processes of various kinds have caused an increase in fertility.' It is now recognized that side by side with all conscious artificial breeding there is at work, more or less actively, a certain natural selection. It has been shown that from a very varied population of types, such as that represented by an F_2 generation of an interracial cross, natural selection eliminates a number of types with astounding rapidity. In such populations within about ten years often up to about 75 per cent of all the types originally present die out, although complete uniformity of the surviving type is not attained. It is also clear that if the same initial population is cultivated as a parallel test under different conditions of soil and climate, selection in the different places acts in different directions ; in each place a different mixture of lines survives. Experimental evidence as to how artificially produced auto-polyploids react to their normal and changed environments is rather meagre. Thanks to the discovery of Blakeslee and others who have given us an easy method of producing artificial auto-polyploids in large numbers, this line of study is receiving greater attention. If auto-polyploids, which usually show a large range of variability in the induced characters, are grown over a long period of time and in different localities subjecting them to natural and artificial selection, sufficient data would be obtained with regard to evolutionary trends.

To test the utility of these gram tetraploids, they will now be grown in large numbers in different tracts for a number of years in bulk and the final types will be studied and subjected to artificial selection later on. The same will be done with artificial polyploids of other crop plants produced in the

Institute and the data that will be obtained are expected to give interesting results. It is, of course, understood that natural selection does not always act in the directions desired by the breeder, but conscious selection in the later stages may help to isolate the desired types. In this connection another possible use of auto-polyploids may be mentioned and that is the formation of new allo-polyploids by hybridization of different auto-polyploids, as for example, *Iris Syndetica* [Simonet, 1935].

Another possibility of the utilization of this discovery for breeding in the case of inter-racial crosses is also indicated by Blakeslee [1939]. In nearly every case of inter-racial crosses, which produces fertile progenies, a large number of mendelian factors are at work, so that in the F_2 generation the number of combinations to be expected is very great. Excepting in the case of vegetatively propagated plants, the task of finding in the F_2 or later generations an individual with desired characters in a homozygous condition is full of difficulties. A large number of plants will have to be sown and for many generations to get the desired result. In such a case, Blakeslee thinks that if we could find out a method whereby haploids could be produced by parthenogenesis, the task of getting homozygous diploids in the F_2 generation is made easy by the application of this method. Starting with a highly heterozygous plant, such as a fertile species hybrid, haploids produced from it by parthenogenesis of reduced eggs will contain only one kind of each chromosome, and now if the haploids are doubled by colchicine, homozygous seeds with each chromosome duplicated will result. The plants from these seeds will be homozygous containing different combinations of the genes of the parents, and selection among them will give the desired results in two jumps. The importance of obtaining homozygous diploids for breeding was also stressed by R. C. C. [1936] when he states that ' instead of growing acres of seedlings and throwing all but a handful away, there may come a time when our future Burbanks will grow acres of haploids to get a few dozen seeds—each one of them representing the beginning of a pure line—which will form the basis of later breeding experiments.' Now that we have a means of readily doubling the chromosome number of the haploids, the great need in our genetic programme is to discover a method whereby the chromosome number in a plant could be halved at will.

SUMMARY

Germinating seeds of gram I P 25 were subjected to varying treatments with colchicine and the C_1 and C_2 plants studied with reference to induced polyploidy. Treatment of seeds with 0·25 per cent aqueous solution of colchicine for half an hour gave the best result from the points of view of survival of seedlings and induction of polyploidy. In the generation immediately following the treatments, the affected plants showed a mixture of $2n$ and $4n$ tissue and in the subsequent generation pure tetraploids were obtained.

A quantitative study of the morphology of the diploid and tetraploid plants was undertaken and the results showed that the tetraploids possessed a larger number of leaves per plant, bigger leaflets, bigger flowers, bigger pods and seeds than the diploids. The pollen grains and the stoma guard cells of the tetraploid were also bigger than those of the diploids, although the pollen

grains of the former were 'about 40-80 per cent sterile compared to only 0-10 per cent sterility of the latter. With regard to height of plants the tetraploids did not vary significantly from the diploids although the latter had significantly more branches than the former.

The chromosome numbers of the tetraploids and diploids were determined as 32 and 16 respectively. The meiosis in the tetraploids was fairly regular with the formation of varying numbers of quadrivalents at diakinesis and metaphase I, seven quadrivalents per cell occurring most frequently. One tetraploid plant, however, showed a chromatin bridge and a fragment in a few cells at anaphase I. The tetraploid plants gave rise invariably to tetraploid progenies.

The significance of the use of colchicine for practical breeding is discussed.

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REFERENCES

Aase, H. C. (1930). The cytology of *Triticum, Secale* and *Aegilops* hybrids with reference to phylogeny : *Res. Stud. St. Coll. Wash.* **2**, 3-60

——————— (1935). Cytology of Cereals : *Bot. Rev.* **1**, 467-96

Afzelius, K. (1924). Embryologische und Zytologische Studien in *Senecio* Und Verwandten Gattungen : *Acta Hort. berg.* **8**, 123-219

Amin, K. C. (1940). A preliminary note on interspecific hybridization and use of colchicine in cotton : *Curr. Sci.* **9**, 74-5

Avdulov, N. P. (1937). The Karyotype of *Cicer arietinum* L. *Abhandlungen der Tschernschewsky Staatsuniversitat Saratow* **1**, 30-6

Babcock, E. B. (1934). Genetic evolutionary processes : *Proc. nat. Acad. Sci. Wash.* **20**, 510-5

Beasley, J. O. (1940). The production of polyploids in *Gossypium* : *J. Hered.* **31**, 39-48

Blakeslee, A. F. (1921). Types of mutations and their possible significance in evolution : *Amer. Nat.* **55**, 254-67

——— ————(1939). The present and potential service of chemistry to plant breeding : *Amer. J. Bot.* **26**, 163-72

Blakeslee, A. F. and Avery, P. (1937). Methods of inducing chromosome doubling in plants : *J. Hered.* **28**, 393-411

Clausen, J. (1926). Genetical and cytological investigations in *Viola tricolor* L. and *Viola arvensis* Murr. *Hereditas, Lund* **8**, 1-156

Clausen, R. E., and Goodspeed, T. H. (1925). Interspecific hybridization in *Nicotiana*, II. A tetraploid *glutinosa—Tabacum* hybrid—an experimental verification of Winge's hypothesis : *Genetics* **10**, 278-84

Dermen, H. (1940). Colchicine polyploidy and technique : *Bot. Rev.* **6**, 599-635

Dixit, P. D. (1932). A note on the cytology of the ' Kabuli ' and ' Desi ' gram types : *Indian J. Agric. Sci.* **2**, 391-408

Dombrowsky-Sludsky, L. (1927). La cinése somatique de *Cicer arietinum* L. (Russian, French, resumé) : *J. Soc. Bot. Russe* **12**, 163-72

Dorsey, E. (1936). Induced polyploidy in wheat and rye : *J. Hered.* **27**, 154-60

Fyfe, J. L. (1939). The action and use of colchicine in the production of polyploid plants : *Imp. Bur. Pl. Br. and Genet., Cambridge*

Greenleaf, W. H. (1938). Induction of polyploidy in *Nicotiana* by heteroauxin treatment : *J. Hered.* **29**, 451-64

Harland, S. C. (1940). New polyploids in cotton by the use of colchicine : *Trop Agriculture, Trin.* **17**, 53-4

Ichijima, K. (1934). On the artificially induced mutations and polyploid plants of rice occurring in subsequent generations : *Proc. Imp. Acad., Japan* **10**, 388-91

Iyengar, N. K., (1939). Cytological investigations on the genus *Cicer* : *Ann. Bot., Lond.* (N. S.) **3**, 271-306

Jorgensen, C. A. (1928). The experimental formation of heteroploid plants in the genus *Solanum* : *J. Genet.* **19**, 133-211

Karpechenko, G. D. (1927). Polyploid hybrids of *Raphanus sativus* L. × *Brassica oleracea* L. : *Bull. Appl. Bot.* **17**, 305-410

Kasparayan, A. S. (1940). A colchicine-induced amphidiploid—Upland × Egyptian cotton (*G. hirsutum* L. × *G. barbadense* L.) : *C. R. (Doklady) Acad. Sci., U. R. S. S.* **26**, 163-5

Katayama, Y. (1935). Karyological comparisons of haploid plants from octoploid *Aegilotricum* and diploid wheat : *Jap. J. Bot.* **7**, 349-80

Kostoff, D. (1936). The origin of cultivated tobacco : *Curr. Sci.* **4**, 872

——— (1937). Chromosome alterations by centrifuging : *Science* **86**, 101

——— (1938, 1). Effect of centrifuging upon the germinated seeds from various plants : *Cytologia, Tokyo* **8**, 420-42

——— (1938, 2). Irregular mitosis and meiosis induced by acenaphthene : *Curr. Sci.* **6**, 549-52

——— (1938, 3). Directed heritable variations conditioned by euploid chromosome alterations : *J. Genet.* **36**, 447-68

——— (1938, 4). Polyploid plants produced by colchicine and acenaphthene : *Curr. Sci.* **7**, 108-10

Kostoff, D. and Kendall, T. (1932). Origin of a tetraploid shoot from the region of a tumour on tomato : *Science* **76**, 144

Levan, A. (1940). The effect of acenaphthene and colchicine on mitosis of *Allium* and *Colchicum* : *Hereditas, Lund* **26**, 262-76

Lindstrom, E. W. and Koos, K. (1931). Cytogenetic investigations of a haploid tomato and its diploid and tetraploid progeny : *Amer. J. Bot.* **18**, 398-419

Muntzing, A. (1932). Cytogenetic investigations on synthetic *Galeopsis Tetrahit* : *Hereditas, Lund* **16**, 105-54

——— (1936). The evolutionary significance of autopolyploidy : *Hereditas, Lund* **21**, 263-378

Navashin, M. (1927). Variabilitat des Zellkerns bei *Crepis*—Arten in bezug auf die Artbildung : *Zschr. f. wiss. Biol., Abt. B* **4**, 171-215

——— (1938). Influence of acenaphthene on the division of cells and nuclei : *C. R. (Doklady) Acad. Sci., U. R. S. S.* **19**, 193-6

Nebel, B. R. (1938). Colchicine and acenaphthene as polyploidizing agents : *Nature, Lond.* **142**, 257

Nebel, B. R. and Ruttle, M. L. (1938). The cytological and cytogenetical significance of colchicine : *J. Hered.* **29**, 3-9

Newton, W. C. F. and Pellew, C. (1929). *Primula kewensis* and its derivatives : *J. Genet.* **20**, 405-67

Pal, B. P. and Ramanujam, S. (1939). Induction of polyploidy in chilli (*Capsicum annum* L.) by colchicine : *Nature, Lond.* **143**, 245-6

Peto, F. H. (1936). Heat-induced tetraploidy in barley : *Canad. J. Res.* **14**, 445-7

Randolph, L. F. (1932). Some effects of high temperature on polyploidy and other variations of maize. *Proc. nat. Acad. Sci., Wash.* **18**, 222-9

Rao, N. S. (1929). Further contributions to the cytology of some crop plants of South India : *J. Indian Bot. Soc.* **8**, 201.

R. C. C. (1936). A haploid Marglobe tomato : *J. Hered.* **27**, 433-5

Richharia, R. H. and Kalamkar, R. J. (1938). Green-seeded gram (*Cicer arietinum* L.) in Central Provinces : *Curr. Sci.* **7**, 282

Richharia, R. H. and Persai, D. P. (1940). Tetraploid *til* (*Sesamum orientale* L.) from colchineine treatment : *Curr. Sci.* **9**, 542

Sansome, F. W. (1931). Graft hybrids and induction of polyploids in *Solanum* : *Proc. 9th Int. Hort. Cong.* 92-9

Simonet, M. (1935). Conjugaison autosyndetique des chromosomes a la meiose de quelques hybrides interspecifiques d' Iris : *Bull. Biologique de la France et de la Belgique* **69**, 178-212

Skovsted, A. (1934). Cytological studies in cotton, II. Two interspecific hybrids between Asiatic and New World cottons : *J. Genet.* **28**, 407-24

Smith, H. H. (1939). The induction of polyploidy in *Nicotiana* species and species hybrids : *J. Hered.* **30**, 291-306

Stebbins, G. L. Jr. (1940). The significance of polyploidy in evolution : *Amer. Nat.* **74**, 54-66

Warmke, H. E. and Blakeslee, A. F. (1939). Induction of tetraploidy in *Nicotiana sanderae* and in the sterile hybrid (*N. Tabacum* × *N. glutinosa*) by colchicine treatment: *Genetics* **24**, 109-10

Zhebrak, A. R. (1939, 1). Amphidiploids of hard wheat and einkorn produced through colchicine treatment : *C. R. (Doklady) Acad. Sci., U. R. S. S.* **25**, 53-5

——————— (1939, 2). Production of amphidiploids of *Triticum durum* × *Triticum Timopheevi* : *C. R. (Doklady) Acad. Sci., U. R. S. S.* **25**, 56-9

STUDIES IN THE TECHNIQUE OF FIELD EXPERIMENTS

V. SIZE AND SHAPE OF BLOCKS AND ARRANGEMENT OF PLOTS IN COTTON TRIALS

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(With two text-figures)

THE application of statistical methods to agricultural research has led to two important developments. On the agronomic side, complex experiments enabling the experimenter to test the simultaneous effect of two or more treatments have become common, while with the growing appreciation that statistical methods are as necessary and appropriate in plant breeding as in agronomic research, breeders have started to undertake properly laid-out varietal trials containing an increasing number of varieties. To maintain an adequate level of accuracy in experimental comparisons, however, the size of block and consequently the number of treatments or varieties to be included in it cannot be increased beyond a limit. To keep the block size small, experimental designs have been evolved in which by adopting ' confounding ' it is possible to include in one block only a part of the total number of treatments or varieties to be tested [Fisher, 1936 ; Yates, 1936, 1, 2].

The gain in accuracy due to smaller blocks resulting from confounding is offset by certain disadvantageous features. In confounding treatments, comparisons of high order interactions which are considered relatively unimportant are either partially or completely lost. With varieties all comparisons are of equal interest and the theoretical efficiency of confounded arrangements is lower than of an ordinary randomized block lay-out ; but this is expected to be more than counterbalanced by a reduction in the actual error variance. Moreover, all varieties in a trial cannot, in some confounded designs, be compared with the same level of accuracy. With the complexity of design, greater care in field work is necessary and the arithmetical computations in the statistical analysis of the results become rather intricate. For these reasons, an experimenter would not wish to sacrifice the simplicity and flexibility of ordinary randomized blocks by adopting confounding, unless there is a possibility that the desired standard of accuracy cannot be attained by employing a simple lay-out. A knowledge of the change of efficiency with increasing size of block in simple randomized block trials is, therefore, of considerable practical interest in setting an upper limit to the size of block and hence to the number of treatments or varieties which can be tested without resorting to complex experimental design.

While discussing the efficiency of different designs, Yates [1935] has pointed out the need of investigating the increase in experimental error due to increased size of block. With the rapid development of experimental work in cotton conducted at the Institute, this need was increasingly felt and an investigation was carried out with the help of data from a uniformity trial described by Hutchinson and Panse [1935]. The results are presented in this paper. The relative accuracy of alternative designs based on confounding is also discussed. While the conclusions are subject to the usual limitations attached to the results of a single experiment, experience has shown that the previously published results [Hutchinson and Panse, 1935] from this uniformity trial have provided a useful guidance for conducting cotton trials in various parts of Central India and Rajputana, and it is hoped that the present conclusions will similarly be applicable over a wide range of conditions.

METHOD OF ANALYSIS

The uniformity trial, it will be remembered, consisted of 1,280 units square in shape and 1/2,000 acre in area. There were 40 units along the length of cotton rows and 32 units across the rows. The yields of unit plots are given in the appendix.

For the purpose of the present investigation, plots of four sizes, 1/50, 1/100, 1/200 and 1/500 acre, were considered. The first two sizes are normally used in agricultural trials, while the last two represent small plots which are necessary under certain conditions, as, for example, when the amount of seed or land is limited. Subject to the restriction that the whole area of the uniformity trial was utilized in every combination, plot shape was also varied and both long and narrow plots as well as more compact ones were examined. Plots of each size and shape were grouped together in blocks of 2, 4, 8, 16 or more plots, 160 being the maximum number of plots per block when plot size was 1/500 acre. Plots were arranged in one or more rows to form a block. In all, 108 combinations were analysed.

The advantage of using blocks in reducing experimental error by removing a larger proportion of variability is expressed as block efficiency. This is a ratio of the error variance that would have been obtained if there were no blocks to that actually obtained after eliminating differences due to blocks. The advantage due to blocks must be considered to break down when this ratio is in the neighbourhood of unity. As a direct measure of accuracy of any experimental arrangement in blocks, the standard error per cent per plot was also calculated. The results are shown in Table I. To save space arrangements of plots in more than four rows have been omitted as these present no new feature.

BLOCK EFFICIENCY

The importance of block size, block shape and arrangement of plots in determining efficiency was indicated in the previous analysis of this uniformity trial [Hutchinson and Panse, 1935]. Table I furnishes more extensive material for studying these points.

TABLE I

Block efficiency and standard error per cent for plots and blocks of different sizes and shapes

Size of block		Plots in one row			Plots in two rows			Plots in four rows		
No. of plots	Area (acre)	Block shape*	Efficiency	S. E. (per cent)	Block shape	Efficiency	S. E. (per cent)	Block shape	Efficiency	S. E. (per cent)
(a) Plot size 1/500 acre, plot shape 4 : 1*										
2	1/250	2 : 1	2·45	14·32						
4	1/125	1 : 1	2·41	14·42	4 : 1	1·70	17·17			
8	1/62·5	1 : 2	2·06	15·61	2 : 1	1·70	17·16			
16	1/31·25	1 : 4	1·95	16·02	1 : 1	1·57	17·87			
32	1/15·62	1 : 8	1·49	18·36	1 : 2	1·54	18·05			
64	1/7·81				1 : 4	1·35	19·28			
(b) Plot size 1/500 acre, plot shape 1 : 1										
2	1/250	1 : 2	3·01	13·14	2 : 1	2·16	15·53			
4	1/125	1 : 4	2·22	15·30	1 : 1	2·24	15·24	4 : 1	1·63	17·86
8	1/62·5	1 : 8	2·12	15·66	1 : 2	1·97	16·26	2 : 1	1·65	17·75
16	1/31·25	1 : 16	1·47	18·79	1 : 4	1·88	16·62	1 : 1	1·53	18·40
32	1/15·62				1 : 8	1·46	18·86	1 : 2	1·51	18·55
64	1/7·81							1 : 4	1·33	19·75
(c) Plot size 1/200 acre, plot shape 10 : 1										
2	1/100	5 : 1	4·03	9·38						
4	1/50	2·5 : 1	3·57	9·97	10 : 1	1·09	18·02			
8	1/25	1·25 : 1	2·72	11·41	5 : 1	1·17	17·44	20 : 1	0·96	19·19
16	1/12·5	1 : 1·6	2·48	11·96	2·5 : 1	1·14	17·66	10 : 1	0·99	18·94
32	1/6·25	1 : 3·2	1·72	14·34	1·25 : 1	1·14	17·65	5 : 1	0·99	18·88
64	1/3·12				1 : 1·6	1·13	17·75	2·5 : 1	1·01	18·74
(d) Plot size 1/200 acre, plot shape 2·5 : 1										
2	1/100	1·25 : 1	4·00	9·51						
4	1/50	1 : 1·6	2·63	11·73	2·5 : 1	3·33	10·42			
8	1/25	1 : 3·2	2·47	12·09	1·25 : 1	2·62	11·75	5 : 1	1·26	16·92
16	1/12·5	1 : 6·4	1·67	14·70	1 : 1·6	2·40	12·26	2·5 : 1	1·13	17·86
32	1/6·25				1 : 3·2	1·70	14·59	1·25 : 1	1·13	17·85
64	1/3·12							1 : 1·6	1·12	17·94
(e) Plot size 1/100 acre, plot shape 20 : 1										
2	1/50	10 : 1	2·33	7·78						
4	1/25	5 : 1	2·00	8·39	20 : 1	1·21	10·79			
8	1/12·5	2·5 : 1	1·56	9·50	10 : 1	1·00	11·85			
16	1/6·25	1·25 : 1	1·49	9·71	5 : 1	1·00	11·87			
32	1/3·12	1 : 1·6	1·41	9·99	2·5 : 1	1·03	11·69			
(f) Plot size 1/100 acre, plot shape 5 : 1										
2	1/50	2·5 : 1	5·11	7·82						
4	1/25	1·25 : 1	3·36	9·66	5 : 1	1·06	17·21			
8	1/12·5	1 : 1·6	3·04	10·14	2·5 : 1	1·10	16·85			
16	1/6·25	1 : 3·2	1·89	12·87	1·25 : 1	1·14	16·58			
32	1/3·12				1 : 1·6	1·14	16·57			
(g) Plot size 1/100 acre, plot shape 1·25 : 1										
2	1/50	1 : 1·6	2·75	10·76						
4	1/25	1 : 3·2	2·89	10·50	1·25 : 1	3·16	10·04			
8	1/12·5	1 : 6·4	1·77	13·40	1 : 1·6	2·91	10·46	2·5 : 1	1·10	17·03
16	1/6·25				1 : 3·2	1·86	13·10	1·25 : 1	1·13	16·76
32	1/3·12							1 : 1·6	1·14	16·74
(h) Plot size 1/50 acre, plot shape 40 : 1										
2	1/25	20 : 1	1·41	5·86						
4	1/12·5	10 : 1	1·17	6·42						
8	1/6·25	5 : 1	1·05	6·77						
16	1/3·12	2·5 : 1	1·12	6·56						
(i) Plot size 1/50 acre, plot shape 10 : 1										
2	1/25	5 : 1	2·48	6·72						
4	1/12·5	2·5 : 1	1·72	8·07	10 : 1	0·91	11·11			
8	1/6·25	1·25 : 1	1·68	8·15	5 : 1	0·96	10·79			
16	1/3·12	1 : 1·6	1·58	8·42	2·5 : 1	1·03	10·43			
(j) Plot size 1/50 acre, plot shape 2·5 : 1										
2	1/25	1·25 : 1	39·64	8·87						
4	1/12·5	1 : 1·6	3·61	8·91	2·5 : 1	0·99	17·04			
8	1/6·25	1 : 3·2	2·01	11·93	1·25 : 1	1·10	16·11	5 : 1	0·92	17·59
16	1/3·12				1 : 1·6	1·14	15·85	2·5 : 1	0·99	17·00

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*Throughout this paper shape of plots and of blocks is expressed as a ratio of length to breadth. The side along the cotton rows is treated as length and that across the rows as breadth irrespective of magnitude.

An inspection of the table shows that for plots with a given size, shape and arrangement, efficiency gradually decreases with increasing size of block. The largest blocks (1/3·12 acre) have a very poor efficiency everywhere, except when compact blocks of this size are formed by arranging 1/100 or 1/50 acre plots in one row. Blocks of identical size and shape formed by arranging longer plots in one or two rows are more efficient than those with shorter plots of the same size arranged in two or more rows. While the difference is usually small, the advantage in favour of long plots arranged in one row is strikingly shown when blocks of 1/100 acre plots with a shape of 20 : 1 or of 1/50 acre plots with a shape of 10 : 1 are compared with blocks of shorter plots of the same sizes. A reason for this difference is that while variation between blocks of a given size and shape is constant, the total variability of long and narrow plots is less than that of shorter plots of the same size, particularly where the plot size is large.

The influence of block shape on efficiency is observed when blocks of the same size but of different shapes formed with plots of a given size arranged in a given number of rows are compared. The general conclusion is that the more compact blocks have a higher efficiency. Only in 10 out of about 60 comparisons is an opposite tendency observed. In four of these exceptional cases, less compact blocks formed with longer plots show a higher efficiency than more compact blocks with shorter plots. Here the reduction in total variability due to longer plots appears to have outweighed the increased variability between more compact blocks. In three other cases where plots are arranged in two rows, less compact blocks with shorter plots possess a higher efficiency than more compact blocks with longer plots. Probably a new factor is responsible for this discrepancy. Plots arranged in such a way that their ends or shorter sides are in contact will be less strongly correlated than when their longer sides form the common border and will have a greater variability. Variability from this cause will increase as the length of plot increases in proportion to its breadth, leading to a loss of efficiency when long and narrow plots are arranged in two or more rows.

The effect of block shape and of arrangement of plots on efficiency when plots of a given size and shape are selected for experimentation is a point of more direct practical interest. It will be seen from Table I that in the majority of cases arrangement of plots in one row has proved more compact and also more efficient than in two or more rows. Those cases in which arrangement in one or two rows is less compact than in two or four rows respectively are brought together in Table II.

When by arranging plots in two rows instead of one, the length-breadth ratio of blocks is considerably reduced, as from 1 : 16 to 1 : 4 or from 1 : 6·4 to 1 : 1·6, the former arrangement is distinctly more efficient. With short plots of 1/200 or 1/100 acre size, a comparatively smaller change in block shape in the right direction, for example, from 1 : 3·2 to 1·25 : 1, also improves efficiency slightly ; but a similar change brought about by arranging longer plots in two rows is disadvantageous. Even with short plots an arrangement in four rows is less efficient than in two rows for small increases in the compactness of blocks. It would thus appear that unless blocks were made substantially more compact by arranging long plots in two rows or short plots in four or more rows, an arrangement in one row for long plots and in one or two rows for short plots is to be preferred.

TABLE II

Block shape and efficiency when arrangement in two or more rows is more compact

Size of block		Plots in one row		Plots in two rows		Plots in four rows	
No. of plots	Area (acre)	Block shape	Efficiency	Block shape	Efficiency	Block shape	Efficiency
(a) Plot size 1/500 acre, plot shape 4 : 1							
16	1/31·5	1 : 4	1·95	1 : 1	1·57		
32	1/15·62	1 : 8	1·49	1 : 2	1·54		
(b) Plot size 1/500 acre, plot shape 1 : 1							
4	1/125	1 : 4	2·22	1 : 1	2·24		
8	1/62·5	1 : 8	2·12	1 : 2	1·97		
16	1/31·25	1 : 16	1·47	1 : 4	1·88	1 : 1	1·53
32	1/15·62			1 : 8	1·46	1 : 2	1·51
(c) Plot size 1/200 acre, plot shape 10 : 1							
32	1/6·25	1 : 3·2	1·72	1·25 : 1	1·14		
(d) Plot size 1/200 acre, plot shape 2·5 : 1							
8	1/25	1 : 3·2	2·47	1·25 : 1	2·62		
16	1/12·5	1 : 6·4	1·67	1 : 1·6	2·40		
32	1/6·25			1 : 3·2	1·70	1·25 : 1	1·13
(e) Plot size 1/100 acre, plot shape 5 : 1							
16	1/6·25	1 : 3·2	1·89	1·25 : 1	1·14		
(f) Plot size 1/100 acre, plot shape 1·25 : 1							
4	1/25	1 : 3·2	2·89	1·25 : 1	3·16		
8	1/12·5	1 : 6·4	1·77	1 : 1·6	2·91		
16	1/6·25			1 : 3·2	1·86	1·25 : 1	1·13
(g) Plot size 1/50 acre, plot shape 2·5 : 1							
8	1/6·25	1 : 3·2	2·01	1·25 : 1	1·10		

There is one combination with 1/200 acre plots in which a more compact block (shape 1 : 1·6) in one row has proved less efficient than an arrangement in two rows with block shape 2·5 : 1. No explanation can be offered for this result.

STANDARD ERRORS

Standard error per plot is the measure of efficiency of an experimental lay-out. Table I shows that for plots of the same size and shape, the standard error per cent steadily decreases as block efficiency increases ; but comparing plots of different sizes and shapes it is seen that lay-outs with large plots and with long and narrow plots have lower standard errors irrespective of block efficiency. The relation between standard error per cent and block efficiency is well brought out by plotting them on graph paper (Fig. 1).

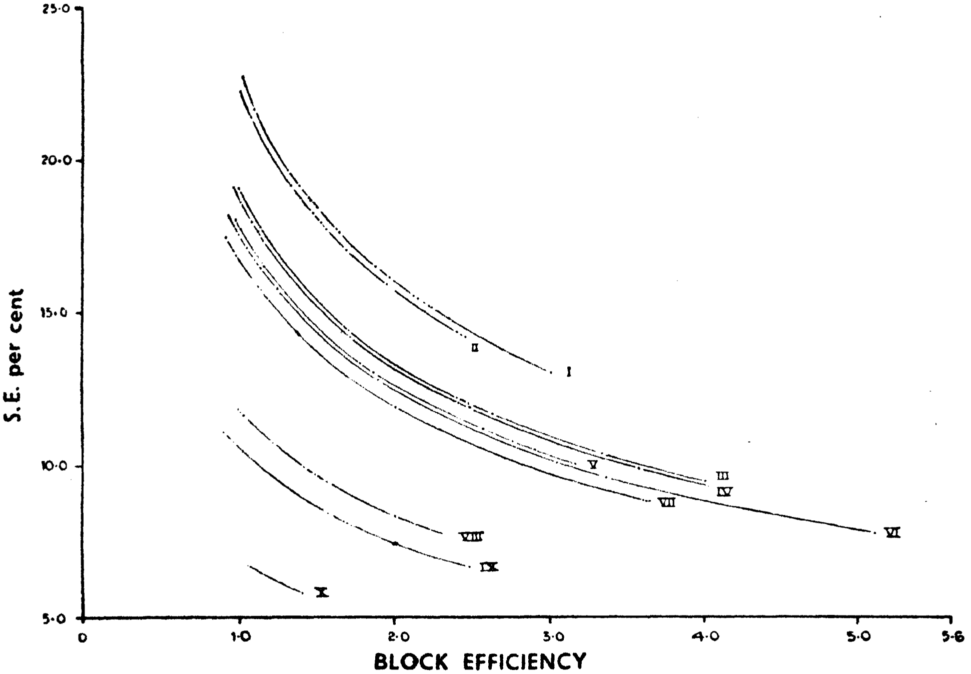

FIG. 1. Relation between standard error per cent and block efficiency

Curve	Plot size (acre)	Plot shape (length : breadth)	Curve	Plot size (acre)	Plot shape (length : breadth)
I	1/500	1 : 1	VI	1/100	5 : 1
II	1/500	4 : 1	VII	1/50	2·5 : 1
III	1/200	2·5 : 1	VIII	1/100	20 : 1
IV	1/200	10 : 1	IX	1/50	10 : 1
V	1/100	1·25 : 1	X	1/50	40 : 1

The points lie on smooth curves, a separate one for plots of each size and shape. The predominant influence of plot size and shape on the standard error of a lay-out is now obvious. Plots of 1/50 acre size generally have the lowest standard error ; but plots of 1/100 acre provided they are sufficiently long and narrow (shape 20 : 1), have a considerably lower error than 1/50 acre plots which are short and broad (shape 2·5 : 1). With the two smaller plot sizes, shape is unimportant, but even here long and narrow plots have a slightly reduced error. With blocks of the same efficiency, experiments with larger and longer plots will have a lower standard error. The efficiency of a lay-out is thus primarily determined by plot size and shape, and after these have been selected, an arrangement giving the maximum efficiency of blocks should be aimed at.

Curves in Fig. 1 represent logarithmic functions and are reduced to straight lines when logarithms of standard error per cent are plotted against those of block efficiency. They are shown in Fig. 2.

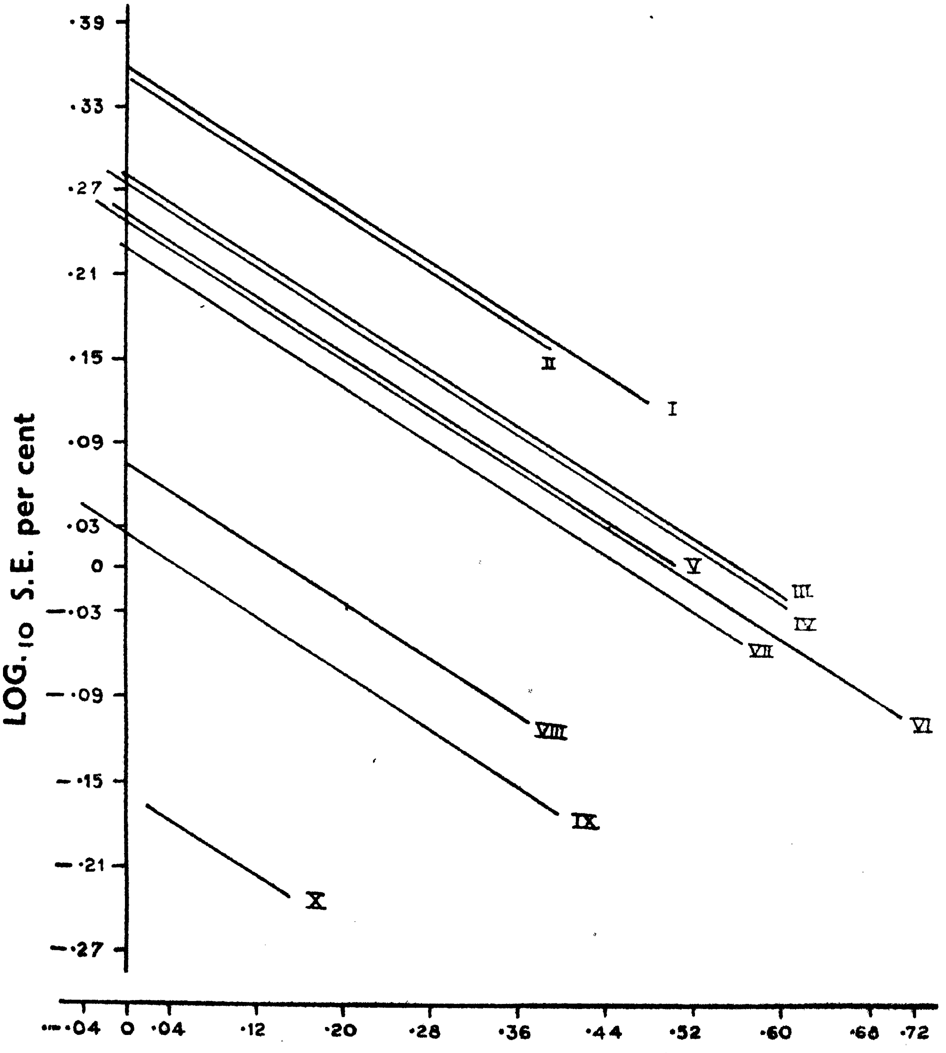

Fig. 2. Relation between logarithms of standard error per cent and of block efficiency

Curve	Plot size (acre)	Plot shape (length : breadth)	Curve	Plot size (acre)	Plot shape (length : breadth
I	1/500	1 : 1	VI	1/100	5 : 1
II	1/500	4 : 1	VII	1/50	2·5 : 1
III	1/200	2·5 : 1	VIII	1/100	20 : 1
IV	1/200	10 : 1	IX	1/50	10 : 1
V	1/100	1·25 : 1	X	1/50	40 : 1

Equations of these straight lines are of the form, $\log y = a - b \log x$, and corresponding equations for the curves drawn in Fig. 1 are,

$$y = 10^a x^{-b},$$

where x and y are block efficiency and standard error per cent respectively. The values of constants a and b can be easily obtained by solving the equations for the straight lines. The value of constant a ranges between $1 \cdot 3574$ and $0 \cdot 8410$, while constant b is approximately $0 \cdot 5$ in all cases. The different lines have thus the same slope or are parallel to one another. This means that for a given change in block efficiency the relative increase or decrease in the magnitude of the standard error is the same for plots of different sizes and shapes.

Constant a represents the logarithm of the standard error per cent when block efficiency is unity, that is when there is no association between neighbouring plots so that the error variance is the same whatever the size and shape of blocks. The ratio of standard errors per cent at this point determines the relative efficiency of blocks necessary to provide the same standard error per cent with plots of different sizes and shapes or the relative magnitude of the standard errors obtained when block efficiency is constant.

In subsequent sections only long and narrow plots of each size will be discussed as being the most efficient.

NUMBER OF PLOTS PER BLOCK

The effect of increasing the size of block on experimental error by including 2, 4, 8, 16, 32 and 64 plots per block may now be considered. Since plots of different sizes and shapes are involved, the relative efficiency of different layouts can be conveniently expressed in terms of the number of replications and the amount of land required to give a desired level of accuracy in making experimental comparisons. A standard error of 4 per cent of the mean is adopted as a standard, enabling differences of 11 per cent or more between two varieties or treatments to be relied upon as significant. The results are given in Table III. If a standard error of 2 per cent is aimed at, the number of replications and the amount of land required will be four times that given in Table III.

A similar table for 4-plot and 8-plot blocks was given previously [Hutchinson and Panse, 1935]. The present table shows that for any number of plots per block, plots of a smaller size require more replications but less total area than larger plots to give a 4 per cent standard error. The reason is that the reduction in plot error is not proportional to the increase in plot size. The conclusions to be drawn from this table regarding the choice of plot size are discussed in the paper referred to and will not be repeated here. It is important to notice for our present object that a lay-out containing up to 16 plots per block can give a 4 per cent error with less than ten replications if plots of 1/200 acre size or larger are employed. This number of replications cannot be considered excessive. Even with blocks of 32 plots, plots of 1/100 acre size require only six replications to give a 4 per cent error. Only the smaller plot sizes, 1/500 and 1/200 acre, were available for making combinations containing 64 plots to a block. With these plots at least 20 replications are necessary to attain a 4 per cent error and here the possible advantage of securing the same standard of accuracy with less replication by resorting to confounding is worth serious consideration. For any number of plots per block, 1/500 acre plots require considerably more replication than other plot sizes and cannot be considered suitable except where the use of such small plots is inevitable.

TABLE III

The number of replications and area of land required to give a standard error of 4 per cent with blocks of different sizes

No. of plots per block	Plot size (acre)	Standard error per cent per plot	No. of replications	Total area (acres)
2	1/500	14·32	13	0·05
	1/200	9·38	5	0·05
	1/100	7·78	4	0·08
	1/50	5·86	2	0·08
4	1/500	14·42	13	0·10
	1/200	9·97	6	0·12
	1/100	8·39	4	0·16
	1/50	6·42	2	0·16
8	1/500	15·61	15	0·24
	1/200	11·41	8	0·32
	1/100	9·50	5	0·40
	1/50	6·77	3	0·48
16	1/500	16·02	16	0·51
	1/200	11·96	9	0·72
	1/100	9·71	6	0·96
	1/50	6·56	3	0·96
32	1/500	18·05	20	1·28
	1/200	14·34	13	2·08
	1/100	9·99	6	1·92
64	1/500	19·28	23	2·94
	1/200	17·75	20	6·40

CONFOUNDING

The gain in efficiency due to confounding is derived from a sub-division of each replicate into smaller blocks. In the analysis of variance, a sum of squares corresponding to differences between sub-blocks is removed from error in addition to the sum of squares due to complete replicates and the error variance is consequently further reduced. The advantage due to confounding will depend upon the magnitude of this reduction in the error variance. Table IV is arranged to compare confounded arrangements with ordinary randomized blocks containing 16, 32 and 64 plots. The gain due to confounding is reflected in the reduced number of replications necessary to give a 4 per cent error. It is more precisely shown by the relative efficiency of the confounded arrangements.

TABLE IV

Relative efficiency due to confounding and number of replications and area of land required to give a standard error of 4 per cent

No. of plots per replicate	Plot size (acre)	Without confounding			Confounded arrangements				Relative efficiency due to confounding
		S. E. per cent per plot	No. of replications	Total area (acres)	No. of plots per sub-block	S. E. per cent per plot	No. of replications	Total area (acres)	
16	1/500	16·02	16	0·51	4	14·42	13	0·42	1·234
	1/200	11·96	9	0·72	4	9·97	6	0·48	1·438
	1/100	9·71	6	0·96	4	8·39	4	0·64	1·339
	1/50	6·56	3	0·96	4	6·42	2	0·64	1·045
32	1/500	18·05	20	1·28	8	15·61	15	0·96	1·336
					4	14·42	13	0·83	1·565
	1/200	14·34	13	2·08	8	11·41	8	1·28	1·579
					4	9·97	6	0·96	2·067
	1/100	9·99	6	1·92	8	9·50	5	1·60	1·105
					4	8·39	4	1·28	1·417
64	1/500	19·28	23	2·94	16	16·02	16	2·05	1·447
					8	15·61	15	1·92	1·524
					4	14·42	13	1·66	1·786
	1/200	17·75	20	6·40	16	11·96	9	2·88	2·200
					8	11·41	8	2·56	2·418
					4	9·97	6	1·92	3·165

The relative efficiency due to confounding is simply the ratio of efficiency of smaller blocks in the confounded arrangement to that of blocks corresponding to a complete replication. Reduction in block size to a quarter or less by confounding has resulted in an appreciable gain in efficiency except only in two cases where it is 10 per cent or less. Plots of 1/50 and 1/100 acre size are involved in these two cases and a reference to Table I will show that with these plot sizes the difference in the efficiency of blocks containing four or more plots and eight or more plots respectively is quite small. Moreover, since with 1/50 acre plots the efficieney of blocks of this size is low, no advantage is to be expected by adopting confounding for this plot size. With 1/100 acre plots the gain in efficiency will be appreciable only when the sub-blocks contain less than eight plots. For the two smaller plot sizes there is a considerable reduction in block efficiency with increasing block size throughout the observed range, and with these plots, confounding has proved more profitable than with larger plots. The gain due to confounding is also naturally greater when there is a larger number of plots in each replicate.

Arrangement of varieties in quasi-factorial or symmetrical incomplete block lay-outs is analogous to confounding, but with one difference. Here we are interested in the comparison of individual varieties and all comparisons are therefore of equal importance. This has the effect of increasing the variance of the comparisons by a factor depending on the number of varieties to be tested and the type of design. This point must be taken into consideration in studying the relative efficiency of varietal trials in incomplete block lay-outs.

For a two-dimensional quasi-factorial arrangement with two equal groups of sets, the mean variance of all comparisons between two varieties is $\frac{2s^2}{r}\,\frac{p+3}{p+1}$ where s^2 is the error variance, r is the number of replications of each variety and p is the number of varieties in each set [Yates, 1936,1]

This means that the error variance given by this arrangement must be further multiplied by $\frac{p+3}{p+1}$ to compare its efficiency with that of ordinary randomized blocks. The corresponding factor for a three-dimensional design with three equal groups of sets is $\frac{2p^2+5p+11}{2(p^2+p+1)}$. For symmetrical incomplete blocks with p^2 varieties, the factor is $\frac{p+1}{p}$ and a minimum of $p+1$ replications are required [Yates, 1936, 2].

With 16 varieties a two-dimensional quasi-factorial arrangement with four varieties in each block is possible. Sixty-four varieties can be similarly tested in blocks of eight. Sixty-four being a complete cube, a three-dimensional quasi-factorial design is also available. If a symmetrical incomplete block lay-out is used, a minimum of five replications for 16 varieties and nine for 64 varieties will be necessary. The relative efficiency of the two quasi-factorial arrangements was calculated and is given in Table V The number of replications and total area required to give a significant difference of 11 per cent between two varieties, which is equivalent to a 4 per standard error of the mean, are also shown.

TABLE V

Relative efficiency and number of replications required to give a 4 per cent standard error for two and three dimensional quasi-factorial designs

Plot size (acre)	Arrangement	Relative efficiency	No. o replications	Total area (acres)
1/500	4 × 4 two-dimensional quasi-factorial	0·881	18	0·58
1/200	4 × 4 two-dimensional quasi-factorial	1·027	9	0·72
1/100	4 × 4 two-dimensional quasi-factorial	0·956	6	0·96
1/50	4 × 4 two-dimensional quasi-factorial	0·746	4	1·28
1/500	8 × 8 two-dimensional quasi-factorial	1·249	19	2·43
1/200	8 × 8 two-dimensional quasi-factorial	1·982	10	3·20
1/500	4 × 4 × 4 three-dimensional quasi-factorial.	1·190	20	2·56
1/200	4 × 4 × 4 three-dimensional quasi-factorial	2·110	9	2·88

The theoretical loss of efficiency with quasi-factorial arrangements is such that with only 16 varieties the reduced size of block has not been able to overcome the loss for any plot size. The simpler arrangement in ordinary randomized blocks is thus also the more efficient one for testing this number of varieties. For 64 varieties, on the other hand, the 8×8 arrangement has proved advantageous, particularly with plots of 1/200 acre. The alternative arrangement in 4×4×4 is not more efficient and cannot be considered suitable for this number of varieties owing to its greater complexity. It may be noted that the number of replications necessary to give a 4 per cent error by adopting a quasi-factorial lay-out when 16 or 64 varieties are under trial, is not less than the minimum required for a symmetrical incomplete block arrangement. The latter besides being slightly more efficient is characterized by simplicity in statistical analysis and equal precision of all comparisons and is therefore to be preferred to quasi-factorial designs in such cases.

DISCUSSION AND CONCLUSIONS

Designs for field experiments have, as their basis, the fact that adjacent areas are more strongly correlated than distant areas. As a consequence of this correlation, plots of a large size and long and narrow shape, small compact blocks and arrangement of plots in one row, particularly with long plots, should be most efficient in reducing experimental error. The results obtained from the analysis of the present uniformity trial are in accordance with this expectation. They are further useful in showing the possible limits up to which advantage of the favourable interaction between the various factors affecting experimental error can be taken in planning experiments under similar conditions.

By applying the method of regression to the analysis of uniformity trial data, Smith [1938] has established an empirical relationship of considerable general interest between plot size and variability. The relationship is of the same form as that shown above between block efficiency and coefficient of variability. In using this relationship to evaluate the optimum size of plots and blocks, shape, however, has been neglected. Smith recognizes the possible influence of plot and block shape on variability ; but his own uniformity trial was too small (the largest plot size was only 1/726 acre) to demonstrate it clearly. It is yet interesting to note that the increased scatter of points with increasing plot size in the diagram in Smith's paper showing the logarthmic relationship between plot size and variability is presumably due to the greater effect of plot shape on variability as plot size increases. An inspection of the table giving variances of plots of different sizes and shapes reveals that for the larger sizes longer plots are generally less variable. Smith's method provides estimates of average relative efficiencies of varying sizes of plots and of blocks ; but in view of the present results these would appear to be of very limited practical value. Changes in the shape of plots and blocks and in the arrangement of plots have been shown to produce considerable variation in the efficiency of any particular size of plot or block, and it does not appear likely that these factors can be subjected to a simple statistical treatment. The somewhat laborious examination of individual combinations of varying sizes and shapes of plots with varying sizes and shapes of blocks remains, therefore, the only means of tackling the problem.

An important point in planning experiments at research stations is the cost of experimental work. This will largely depend on the total area under experiments. For testing any number of varieties or treatments, with a desired level of accuracy, small plots have been shown to require less total area than large plots, whatever the type of design adopted. For this reason, the smallest size of plot possible in conformity with agricultural requirements would be considered most economical. Against this, however, must be set the increased labour and equipment necessary for handling a large number of replicates. Considering both factors, small plots would seem to be particularly advantageous when a large number of varieties or treatments is under trial. The possibility of increasing experimental accuracy by adopting confounding is another argument in favour of using small plots under these conditions. With plots of a large size, the efficiency of blocks containing even a small number of plots is too low for confounding to be of any advantage. This has been demonstrated for plots of 1/50 acre size.

With the other three plot sizes, the increase in efficiency due to confounding is 20 - 40 per cent when there are 16 plots to a replicate, sub-divided into 4-plot blocks, but with 32 or more plots per replicate and the same size of sub-blocks the increase is 40 per cent or greater. From these results, confounding appears most likely to be profitable when there are 32 or more treatments in an experiment. With only 16 treatments, the relatively smaller gain from confounding would be desirable if differences between treatments are expected to be small, otherwise the simpler lay-out in ordinary randomized blocks would be preferred. In variety trials the gain in efficiency with quasi-factorial arrangements is less than that with an equivalent degree of confounding in agronomic experiments of the same size. In the present analysis the 4×4 quasi-factorial design with only 16 varieties has proved actually less efficient than ordinary randomized blocks. For a higher efficiency with these designs a considerably larger number of varieties should be under trial.

Where quasi-factorial arrangements are appropriate, the symmetrical incomplete block design deserves particular notice. An essential condition for its use is that a certain minimum number of replications is necessary, this number being $p+1$ when p^2 varieties are to be tested. Thus, for 100 varieties, 11 replications will be the minimum. This cannot be considered excessive, since, as we have seen before, nine replications are required for a quasi-factorial lay-out with 64 varieties to give a 4 per cent error of the mean.

SUMMARY

The relation between block size and experimental error is important in planning agricultural trials. A uniformity trial on Malvi cotton was examined to study the question, by combining plots of 1/50, 1/100, 1/200 and 1/500 acre size into blocks of varying sizes.

There is a general decrease of block efficiency with increasing block size. More compact blocks of the same size show a higher efficiency. Blocks of identical size and shape but consisting of long plots also show a somewhat higher efficiency than blocks with short plots of the same size. Arrangement of plots in more than one row decreases block efficiency and the effect is more pronounced with long plots.

A logarithmic relationship is shown to exist between block efficiency and experimental error ; but larger and longer plots give a lower error irrespective

of block efficiency. In determining experimental error plot size and shape are therefore of greater importance than block efficiency.

The number of replications and total area of land required to give a 4 per cent error of the mean were calculated. For the same number of plots per block, smaller plots require more replication but less total area than larger plots.

With all plot sizes except the largest, and with 16 or more plots to a replicate, there is a gain in efficiency by confounding ; but a quasi-factorial arrangement for only 16 varieties was found less efficient than simple randomized blocks.

Factors influencing the choice of design for agronomic and varietal trials of different sizes are discussed.

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REFERENCES

Fisher, R. A. (1936). *The design of experiments* : Oliver and Boyd, Edinburgh
Hutchinson, J. B. and Panse, V. G. (1935). *Indian J. agric. Sci.* **5**, 523
Smith, H. Fairfield (1938). *J. agric. Sci.* **28**, 1
Yates, F. (1935). *Suppl. J. Roy. Stat. Soc.* **2**, 181
——— (1936, 1). *J. agric. Sci.* **26**, 424
——— (1936, 2). *Ann. Eug.* **7**, 121

APPENDIX

Uniformity trial on Malvi cotton, 1933-34, Institute of Plant Industry, Indore, C. I.

(Yield of seed cotton per plot in gm.)

93	95	111	116	97	82	80	131	80	102	97	95	87	126	118	89	57	106	118	97	72	120	117	117	66	123	116	86	87	79	78	56	1
49	63	50	115	83	78	69	93	85	84	64	69	51	44	115	61	54	54	36	88	62	75	52	91	74	66	76	79	54	54	109	87	2
89	90	95	129	97	133	72	115	97	76	91	106	40	147	119	66	122	63	72	34	47	106	132	97	70	78	56	81	59	81	78	61	3
85	91	115	107	99	77	76	63	70	71	59	78	58	85	61	104	84	104	59	56	70	66	51	83	77	64	87	87	62	80	87	107	4
63	96	68	69	101	120	96	100	70	110	88	75	101	61	106	113	93	62	92	109	84	117	101	75	100	104	129	96	107	116	82	101	5
86	82	118	74	117	28	83	81	109	91	53	108	83	74	129	89	79	89	75	114	106	94	93	71	103	70	63	114	55	92	67	126	6
62	86	119	80	79	92	72	103	89	77	67	88	97	50	101	111	100	96	66	113	98	86	97	69	105	76	87	73	108	104	116	73	7
94	76	119	75	125	96	95	74	90	63	68	66	96	66	85	74	160	148	84	110	110	110	83	154	101	103	89	137	79	111	120	82	8
45	96	115	130	99	77	104	116	64	77	32	88	67	76	72	87	59	123	67	59	113	131	55	101	105	98	98	57	69	78	62	99	9
51	79	111	79	84	84	67	63	66	40	56	80	58	68	52	76	87	72	91	81	153	82	70	133	96	108	68	92	127	91	110	88	10
81	80	72	102	104	81	42	76	85	80	56	74	93	88	60	111	128	124	117	118	77	84	104	105	119	101	104	129	53	62	99	75	11
74	51	66	86	71	73	98	87	61	111	81	61	73	61	63	85	115	80	82	76	86	97	65	75	68	98	67	69	75	89	72	88	12
85	89	112	88	105	76	76	78	72	92	59	81	90	52	82	68	88	94	68	106	87	106	80	88	71	85	82	108	104	98	95	90	13
84	64	101	90	69	101	87	70	63	75	63	88	74	81	68	87	82	80	64	105	67	70	58	79	88	58	73	53	85	64	96	86	14
85	55	88	87	73	119	60	76	60	73	77	44	83	82	74	52	97	65	59	75	110	79	101	74	66	84	87	100	67	83	61	70	15
82	83	102	80	88	57	81	55	75	69	70	84	59	73	77	81	98	74	95	110	119	93	95	81	102	82	74	82	80	75	85	99	16
46	54	83	60	57	75	73	50	60	31	56	66	43	70	59	35	90	62	89	96	87	72	80	88	67	67	107	69	79	48	89	59	17
71	68	39	80	73	86	64	89	101	88	63	83	74	78	74	50	126	98	104	109	45	106	107	100	137	110	102	79	134	45	60	78	18
58	52	85	99	72	96	67	86	37	71	62	48	63	64	106	99	91	86	83	104	55	70	73	67	67	50	91	88	89	70	56	66	19
65	45	77	78	93	60	94	82	72	81	84	64	75	97	114	109	111	74	107	86	53	52	90	53	72	70	43	53	106	49	67	62	20
57	52	60	71	55	89	71	53	64	74	95	59	68	94	85	90	98	94	84	62	60	54	50	35	64	70	54	62	85	77	78	76	21
60	90	65	66	59	55	51	79	80	62	95	94	95	96	114	105	113	49	123	104	60	71	83	81	79	50	69	76	111	79	108	119	22
59	69	39	79	74	68	54	72	69	67	81	72	56	68	92	62	103	39	98	64	115	41	73	99	78	72	104	56	121	80	128	157	23
63	78	60	83	51	60	60	72	75	45	75	69	93	89	75	87	114	147	138	118	106	106	86	85	95	154	78	98	133	125	133	101	24
23	67	47	83	74	58	95	108	81	86	88	99	82	90	133	97	85	113	137	82	130	82	106	96	53	102	103	82	124	108	116	108	25
39	57	83	70	77	89	79	113	77	102	101	74	79	97	100	41	77	98	71	98	102	75	77	83	112	106	95	106	93	68	94	103	26

79	29	57	77	75	82	87	77	61	85	108	65	64	95	56	51	153	116	45	132	103	88	94	123	76	145	103	107	122	94	108	121	27
81	54	74	87	71	74	62	62	90	80	83	60	68	53	82	107	152	40	80	124	130	105	103	69	75	115	138	129	165	135	143	138	28
56	47	86	69	81	60	73	96	73	59	83	83	89	130	74	76	133	30	43	81	96	85	86	140	103	92	88	93	97	38	82	103	29
52	78	62	55	60	58	111	54	87	76	82	103	114	92	70	39	87	35	46	39	52	157	80	63	59	69	63	72	64	68	102	62	30
57	70	68	87	79	89	87	91	85	74	67	98	89	69	50	57	56	54	71	70	69	92	47	41	29	52	46	79	87	74	73	65	31
44	41	81	80	90	78	61	76	78	87	106	41	49	61	70	78	145	40	79	103	71	29	51	28	30	37	37	53	49	81	28	36	32
59	68	44	71	75	79	64	68	62	118	60	78	63	53	67	51	84	40	64	46	34	15	33	56	32	35	42	37	35	97	56	66	33
48	33	65	85	64	74	96	74	95	101	56	59	61	77	57	44	88	91	29	50	40	32	61	47	8	27	54	72	76	67	89	99	34
69	63	68	71	54	59	84	71	84	87	82	73	73	73	48	42	28	36	31	13	17	35	18	24	14	22	33	42	52	82	60	72	35
59	66	95	74	81	77	94	106	132	80	142	30	83	46	56	29	82	25	41	30	23	46	47	35	40	58	63	61	63	92	57	78	36
72	51	66	48	65	82	119	101	90	53	69	66	45	54	61	68	47	44	32	32	50	37	32	53	17	30	43	5	42	36	62	61	37
81	69	58	66	45	77	94	84	98	44	57	58	17	68	45	39	82	61	33	72	65	86	37	57	53	44	47	56	76	56	75	87	38
61	106	43	84	46	74	56	109	115	61	60	39	66	61	57	37	109	71	81	52	79	92	45	62	49	87	111	73	93	58	56	51	39
83	87	69	64	76	82	61	64	87	59	99	31	81	45	50	31	52	40	50	53	57	97	52	81	82	76	54	55	91	12	50	80	40
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	

VARIATION IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

III. VARIATION OF MATURITY AMONG THE DIFFERENT REGIONS OF THE SEED SURFACE

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INTRODUCTION

I

THE halo obtained by combing the fibres on a seed cotton, when observed closely, reveals that the fibres are not uniformly distributed over the entire seed surface. Near the funicle the fibres are few while at the chalazal end they are very densely populated. It has been shown by many workers that the fibres at the latter region are the first to form. These differences in the time of formation and the density of fibre population—leaving alone the changes in the position of vascular strands—may be expected to influence the physical characters of the fibres produced at the different regions of the seed surface. Koshal and Ahmad [1932] have made a detailed study on this point in regard to the properties—length, weight and strength. They find considerable variations in different regions, more especially at the chalazal end. A small study by the writer [Iyengar, 1932] on one cotton indicated somewhat similar differences in length, weight and maturity. The present work is an extension of it, particular attention being paid to the variation of maturity in the different regions. The study has indicated that the immaturity is considerable at the chalazal end. In order to see whether any manurial treatment would be able to mitigate this low maturity, the work was extended to samples obtained from different manurial treatments. The conclusions drawn in this case, however, should be considered tentative as they are derived from a single cotton.

MATERIAL AND METHOD

Fourteen pure strains of cotton formed the material for this enquiry They were all grown in field No. C 1 of the Cotton Breeding Station, Coimbatore, during the season 1932-33. Turner [1929] has dealt with the various factors that induce variability in cotton. In the present enquiry the effects of some of these factors, like the date of picking, the composition of the boll and the lock and the position of the seed in the lock, were minimized by sampling in the manner described below. Single day's picking was taken, only three-locked bolls being picked in all cases except for Verum 262, Gadag 1 and Co 2 where four-locked bolls were picked. From them the middle seed of 7-seeded locks (9-seeded for Co2, Verum 262 and Mollisoni ; 8-seeded for Roseum and

6-seeded for 171 and Chandajari) was taken to make up the sample. The number of seeds in a sample ranged from 30 to 60 in the different varieties. The seeds were carefully combed to form a full halo, care being taken to pull out as few hairs as possible. The ' combed waste ' was also preserved and examined separately.

The surface of the seed was divided into six regions : (1) micropylar end, (2) portion adjacent to the raphe, (3) right side*, (4) left side, (5) back of the seed (that is, antipodes to the raphe) and (6) chalazal end. In order to avoid overlapping, fibres in the borderland were discarded ; from the combed halo, a tuft of fibres sprouting from the region required was separated and pulled out by means of a dissecting needle. Tufts from the same region of other seeds were put together and made into a sliver for the study of the maturity. Clegg's [1932] method was employed and ten tufts of about 100 fibres each were tested for each region.

For the subsidiary study on the effect of manurial treatment, only two regions—the micropylar and chalazal ends of the seed—were considered. The material was of Co 2 obtained from plots laid out for the study of the effects of different mineral manures. Five treatments, namely (1) no manure, (2) N (nitrogenous manure), (3) N and K (nitrogen and potash), (4) N and P (nitrogen and phosphoric acid) and (5) N, K and P (nitrogen, potash and phosphoric acid) were given in each of two fields, 5-b with rich soil, and 3-b with poor soil. Two sets of samples were taken from the two fields by picking on two different dates, *viz.* 28 February 1931 and 7 March 1931. The fifth seed of 9-seeded locks from 4-locked bolls made up the samples. The fibres from the micropylar and chalazal ends only were pulled out as described above and tested for maturity. Incidentally the mean length and the weight per cm. for these samples were determined in order to have an idea of the effect of the manurial treatments on these characters also.

The statistical significance of the differences has been found as follows. In the 14 strains, for the mature and immature fibre percentages, the standard error for each region was calculated by the formula $\sqrt{\frac{pq}{n}}$, where p and q represent the percentages of fibres falling within and outside the particular class under study and n the total number of fibres examined. The standard error of the difference between two regions is computed as $\sqrt{s_1^2+s_2^2}$, s_1 and s_2 being the standard errors for the two respective regions. In the study of the effect of manures analysis of variance was employed.

RESULTS

Fourteen samples

The results for the variation of the mature and immature fibres in the different regions are given in Table I. The percentages of mature fibres may first be considered. It will be seen that at the micropylar end the fibres are very mature, 99 per cent of them being mature in some cottons, the lowest being 90 per cent in the case of Jayawant. The chalazal end exhibits considerable variations in the different strains. Though strains like Roseum,

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* The halo is placed so that the raphe faces the observer and the micropylar end points upwards.

TABLE

Maturity in the different

No.	Species	Strain	Mature fibres percentage											
			Micropylar		Chalazal		Right		Left		Raphe		Back	
			Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.
1	*G. arboreum.*	Roseum	99·1	0·27	86·2	1·03	98·0	0·42	96·4	0·57	96·8	0·50	96·4	0·57
2	,, .	Mollisoni	95·8	0·57	88·5	0·92	96·0	0·56	95·5	0·61	95·0	0·62	91·7	0·82
3	,, .	Cocanadas 171	97·7	0·44	76·7	1·28	97·1	0·51	96·9	0·53	95·6	0·61	94·6	0·67
4	,, .	Chandajari	98·9	0·30	69·2	1·35	96·3	0·57	96·5	0·51	97·5	0·45	96·6	0·51
5	,, .	*Sanguineum*	97·9	0·42	61·5	1·37	96·4	0·54	93·5	0·72	93·0	0·74	90·0	0·86
6	,, .	N 14 .	95·5	0·59	63·3	1·34	95·5	0·58	89·0	0·89	92·0	0·74	95·0	0·57
7	,, .	Bani 306	97·9	0·43	47·2	1·37	90·6	0·84	91·3	0·71	81·2	1·09	89·4	0·84
8	,, .	Karunganni C 7	98·8	0·32	34·1	1·40	88·7	0·91	80·0	0·94	94·4	0·67	83·9	1·06
9	, .	Verum 262	95·6	0·56	28·2	1·18	88·4	0·89	87·1	0·89	90·8	0·81	87·3	0·97
10	*G. herbaceum.*	H 1 .	95·9	0·59	91·7	0·77	96·1	0·57	96·5	0·55	97·1	0·49	91·8	0·79
11	,, .	2405 .	97·4	0·46	83·0	1·05	92·7	0·77	95·3	0·64	95·3	0·57	93·8	0·72
12	,, .	Jayawant	90·1	0·84	69·8	1·36	85·7	1·06	88·6	0·93	91·6	0·78	82·5	1·05
13	*G. hirsutum*	Gadag 1	97·6	0·42	85·5	1·00	96·3	0·53	96·8	0·48	97·6	0·42	94·0	0·43
14	,, .	Co 2 .	94·1	0·76	36·6	1·48	77·9	1·21	67·6	1·48	79·1	1·22	77·4	1·34

I

regions of the seed surface

Immature fibres percentage															
Waste		Micropylar		Chalazal		Right		Left		Raphe		Back		Waste	
Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.	Value	S. E.
85·0	1·09	0·2	0·13	2·6	0·47	0·4	0·19	0·5	0·21	0·3	0·16	0·5	0·21	5·9	0·72
74·0	1·30	0·9	0·27	3·5	0·53	0·5	0·20	0·7	0·24	0·9	0·27	1·9	0·41	10·5	0·91
72·0	1·33	0·5	0·21	11·8	0·97	1·0	0·31	1·1	0·32	1·8	0·39	1·7	0·38	18·0	1·13
51·5	1·46	0·2	0·13	10·7	0·90	1·2	0·33	1·6	0·35	0·6	0·22	1·2	0·30	30·4	1·35
73·3	1·30	0·4	0·18	5·2	0·64	0·5	0·21	1·4	0·34	1·2	0·32	2·6	0·46	10·0	0·78
58·5	1·32	0·8	0·25	14·8	0·99	0·8	0·25	5·2	0·63	3·0	0·46	1·3	0·30	30·1	1·23
47·3	1·39	0·9	0·28	31·8	1·12	5·2	0·64	4·5	0·62	11·4	0·88	4·5	0·57	33·8	1·33
41·5	1·47	0·3	0·16	36·4	1·42	4·2	0·58	3·8	0·57	1·7	0·37	6·1	0·69	39·1	1·45
51·4	1·35	0·7	0·23	33·2	1·24	2·7	0·45	3·8	0·51	2·4	0·43	4·3	0·59	27·6	1·21
85·9	1·02	0·9	0·28	22·4	0·43	0·5	0·21	0·7	0·25	0·9	0·27	2·9	0·47	4·4	0·60
83·0	1·12	0·3	0·18	5·1	0·61	1·2	0·32	0·6	0·23	0·8	0·24	1·1	0·31	3·4	0·54
53·0	1·43	1·8	0·38	9·8	0·88	4·5	0·61	2·9	0·49	2·6	0·45	6·2	0·67	18·2	1·11
74·2	1·26	0·1	0·09	1·0	0·27	0·3	0·15	0·4	0·17	0·2	0·12	0·4	0·17	4·2	0·58
45·8	1·54	2·1	0·46	39·8	1·50	10·4	0·89	15·9	1·16	12·7	1·00	9·7	0·92	42·7	1·58

Mollisoni, H 1, 2405 and Gadag 1 have fairly high percentages, there are others which have very small percentages. For example Verum 262 records the lowest figure of 28 per cent, Karunganni C 7 has 34 per cent, while Co 2 has 37 per cent. In all the strains this region has a significantly lower figure than the micropylar end.

The other four regions may be considered together, for though some of the differences are statistically significant, generally speaking the variation among these four regions, within a strain, is not large. The raphe region of Bani 306 and the back region of Karunganni C 7 and Jayawant exhibit significantly lower maturity than the others of the four regions of the respective strains. For N 14 the left side indicates a lower maturity than the right and back regions. In Co 2 the left side is significantly less mature than the raphe and back regions. In view of the negligibility of the differences between the right and left sides in all the others, except N 14, this huge difference observed is rather surprising.

When the maturity of these regions is compared with that for the chalazal end all differences, except one (H 1 back region), are statistically significant. When compared with that for the micropylar end, Bani 306, Karunganni C 7, Verum 262 and Co 2 exhibit significantly lower percentages. In other cases the differences are not significant.

When the maturity figures of the combed waste are considered, it will be seen that generally they are nearly the same as for the chalazal end, though in some cases it is more and in some others less.

The values for the immature fibres may now be considered. It will be seen that the variations of this figure corroborate the statements made above according to the mature fibres, and therefore need not be repeated. In this case also the left side of Co 2 indicates lesser maturity than the right side and back, though not as low a maturity as was exhibited by the mature fibres.

Summing up the above, it may be stated that: (1) the fibres at the micropylar end are very mature; (2) at the chalazal region the maturity varies considerably in the different strains; the maturity for this region is, however, significantly less than that for the other regions in all cases except one; (3) among the other four regions the differences are generally not considerable; in only four strains is the maturity of these regions significantly less than that for the micropylar end.

Effect of manurial treatment

It has been found above that generally it is the chalazal end that contains high percentage of immaturity. It was thought valuable to study if any manurial treatment would enable this region to improve its maturity. Samples from plots obtaining different mineral manurial treatments which were available were utilized for this enquiry. It should be mentioned at the outset that the conclusions drawn in the following should be considered tentative only on account of (1) the results being obtained for only one cotton and (2) the number of replications and consequently the number of degrees of freedom for the error variance being not large. The results are recorded in Table II. It will be seen that the micropylar end records high percentages with very small variations. At the chalazal end, however, the differences are fairly large in some cases. In the rich field (5-b) the differences between the treatments are very small for the picking of 28 February excepting for the high value 34 per cent for treatment N. For the other picking of 7 March apparently a small improvement is indicated with the supply of better nutriment, but the differences are small and not significant. In the poor field (3-b), on the other hand, there is a significant improvement of maturity with improved plant food in both the pickings. In view of this trend it is rather surprising why the better nutrition available in the rich field has produced lower maturity (28·6), especially in the picking of 28 February. The cause remains unknown.

To assess the statistical significance of the maturity, in this case, the maturity ratio of Peirce and Lord [1939] would be the appropriate measure. It takes into account the percentages of the three maturity classes and expresses the maturity as a single factor. These values also are given in Table II and the statistical analysis of them is found in Table III.

TABLE II

Variation of maturity with manurial treatment

Property	Treatment	Micropylar end					Chalazal end				
		5-b		3-b		Mean	5-b		3-b		Mean
		28-2	7-3	28-2	7-3		28-2	7-3	28-2	7-3	
Mature fibres (per cent)	No manure	92	96	97	97	96·0	28	33	24	31	29·0
	N	98	94	96	96	95·5	34	34	32	35	33·8
	N + K	96	96	97	96	96·2	26	35	30	37	32·0
	N + P	96	97	96	98	96·8	28	36	39	41	36·0
	N + K + P	96	95	98	98	96·8	27	37	43	46	38·0
	Mean	95·6	95·6	96·8	97·0	96·3	28·6	35·0	32·6	38·0	33·8
	Fields	95·6		96·9			31·8		35·8		
	Pickings		96·2	96·3				31·1	36·5		
Immature fibres (per cent)	No manure	0·9	0·7	0·7	0·5	0·7	24	24	26	25	24·8
	N	0·4	0·6	0·6	0·6	0·6	19	21	21	23	21·0
	N + K	0·5	0·8	0·8	0·4	0·6	25	20	21	21	21·8
	N + P	0·6	0·7	0·3	0·4	0·5	24	24	22	18	19·5
	N + K + P	1·0	0·4	0·2	0·2	0·4	20	19	22	17	19·5
	Mean	0·7	0·6	0·5	0·4	0·6	22·4	21·6	22·4	20·8	21·8
	Fields	0·6		0·4			22·0		21·6		
	Pickings		0·6	0·5				22·4	21·2		
Maturity ratio	No manure	1·158	1·174	1·184	1·180	1·174	0·719	0·744	0·692	0·726	0·720
	N	1·186	1·166	1·176	1·178	1·176	0·776	0·769	0·754	0·758	0·764
	N + K	1·178	1·174	1·180	1·178	1·178	0·705	0·774	0·744	0·780	0·751
	N + P	1·180	1·182	1·178	1·188	1·182	0·720	0·760	0·786	0·815	0·770
	N + K + P	1·178	1·173	1·188	1·190	1·182	0·736	0·790	0·806	0·844	0·794
	Mean	1·176	1·174	1·181	1·183	1·178	0·731	0·767	0·756	0·785	0·760
	Fields	1·175		1·182			0·749		0·770		
	Pickings		1·179	1·178				0·744	0·776		

For the micropylar end*, it will be seen, none of the variances are significant. For the chalazal end, however, all the main effects are highly significant besides the first order interaction between field and treatment, indicating that the fields respond differently to the manurial treatments. In the rich field the influence of nutrition is not significant but in the poorer field maturity responds significantly to it, better nutrition causing increased maturity. The difference between the two fields is also significant, the poorer field recording greater maturity, which is rather irreconcilable with the above findings. The picking of 7 March is significantly more mature than that of 28 February.

It will be seen that for the chalazal end the second order interaction is small and according to that all the main effects and the first order interaction between M and F are highly significant. For the study of the main effects the non-significant interactions, M × P and F × P, may be combined with the second order interaction. Even then all the three main effects are significant. If, however, the main effects M and F are compared with their interaction M × F, both of them are non-significant.

II

The results obtained from the incidental study of the length and fibre weight may now be considered.

Only the mean values of the length, weight per cm. and standard fibre weight are given in Table IV for the sake of brevity and the analysis of variance is found in Table III. The figures for the chalazal end alone have been analysed, as greater variability was exhibited by that region, as was found in the case of the maturity.

Before taking up the differences caused by the treatments, the differences between the two regions may be considered. It will be seen that the length at the chalazal end is always greater than at the micropylar end, the difference being about 10·1—13·7 per cent of the former, similar to that got by Koshal and Ahmad [1932].

The fibre weight per cm. is much less at the chalazal end than at the micropylar end as was found by Koshal and Ahmad [1932]. The increase found in the present cotton, Co 2, is, however, higher than what was obtained by them, being as high as about 120 per cent. The low weight at the chalazal end is seen to be accompanied by greater immaturity, whose influence may be eliminated by calculating the standard fibre weight [Peirce and Lord, 1939]. The results for this character, given in Table IV, show that this also is less at the chalazal end. The increase at the micropylar end over that at the chalazal end is about 40 per cent. What was 120 per cent in the case of the fibre weight per cm. has been reduced to 40 per cent, thus indicating that the low fibre weight was partly due to the immaturity and partly to intrinsic fineness of the fibres at the chalazal end. This supports the findings of the writer made in the study of the cell diameter of the uncollapsed fibre, where the chalazal region recorded a significantly lesser diameter than the micropylar region. The average for 17 *hirsutum* cottons was $24 \cdot 7 \pm 0 \cdot 32\mu$ for the micropylar region and $21 \cdot 0 \pm 0 \cdot 26\mu$ for the chalazal region. For the cotton Co 2 it was found to be $26 \cdot 4 \pm 0 \cdot 52\mu$ and $21 \cdot 8 \pm 0 \cdot 34\mu$ respectively for the two regions.

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* The analysis of variance has been carried out separately for the two regions, as it would be incorrect to combine them because the variances for the two regions are not nearly equal or of the same order,

TABLE III

Analysis of variance ; mean square and significance

Variance due to	Degrees of freedom	Maturity ratio: Micropylar end		Maturity ratio: Chalazal end		Mean fibre length in inch		Fibre wt. per cm. in 10^{-6} gm.		Standard fibre wt. in 10^{-6} gm.	
		10^{-3}		10^{-8}		10^{-2}		10^{-2}		10^{-2}	
Manures (M)	4	0·0573	N	2·954	HS	0·052	N	0·066	N	1·459	N
Fields (F)	1	0·2651	N	2·282	HS	0·013	N	1·305	N	0·336	N
Pickings (P)	1	0·0135	N	5·219	HS	0·841	S	1·109	N	0·030	N
Interaction											
$M \times F$	4	0·0443	N	1·627	HS	0·046	N	0·352	N	0·875	N
$M \times P$	4	0·0352	N	0·429	N	0·044	N	0·324	N	0·506	N
$F \times P$	1	0·0090	N	0·045	N	0·004	N	0·080	N	0·014	N
$M \times F \times P$	4	0·0628		0·093		0·046		0·433		0·562	

N = Not significant.
S = Significant for $P = 0 \cdot 05$
HS = Significant for $P = 0 \cdot 01$

TABLE IV

Difference between the micropylar and chalazal ends

Treatment	Mean fibre length in inch: M	C	$\frac{C \sim M}{C} \times 100$	Fibre weight per cm. in 10^{-6} gm.: M	C	$\frac{C \sim M}{C} \times 100$	Standard fibre weight per cm. in 10^{-6} gm.: M	C	$\frac{C \sim M}{C} \times 100$
Manures									
No manure	0·85	0·98	13·3	2·92	1·28	128	2·48	1·77	40·1
N	0·89	1·00	11·0	2·82	1·27	122	2·40	1·66	44·6
N + K	0·90	1·02	11·7	2·82	1·26	124	2·39	1·68	42·8
N + P	0·87	1·00	18·0	2·88	1·26	129	2·44	1·63	49·7
N + K + P	0·89	0·99	10·1	2·84	1·29	119	2·40	1·62	48·2
Fields									
5-b	0·87	1·00	13·0	2·86	1·24	130	2·44	1·66	47·0
3-b	0·88	1·00	12·0	2·86	1·30	120	2·41	1·68	43·5
Pickings									
28 February 1931	0·88	1·02	13·7	2·86	1·24	131	2·43	1·68	44·6
7 March 1931	0·88	0·98	10·2	2·86	1·29	122	2·42	1·67	44·8
Grand mean	0·88	1·00	12·0	2·86	1·26	127	2·42	1·68	44·0

M = Micropylar end ; C = Chalazal end

The variances may now be considered. These are found in Table III It will be seen that all the variances are insignificant, except that for length between pickings. The picking of 28 February indicates a significantly longer length than that of 7 March. All the other differences are insignificant. Neither the manures, nor the field of growth has any marked effect on the length, weight per cm. or the intrinsic fineness.

It is beyond the scope of the present work to consider in detail the effect of manurial treatments. Some findings of the workers on the subject may, however, be given. Nelson and Ware [1932] who made an extensive study of the effect of nitrogen, potash and phosphoric acid found no effect of any of these manures on the staple length. Armstrong and Bennett [1933] found that small plants grown on plots of low fertility and clearly suffering from malnutrition produced lint of practically the same length as that produced by vigorous plants growing in plots of high fertility, though the uniformity of distribution of different lengths was less in the poorly nourished plots. Reynolds and Killough [1933] found no effect of nitrogen and potash but an increase in length 'which approached significance' by phosphoric acid. They concluded that' while some fertilizers appeared to produce significant increases or decreases in the length of lint, it is probable that these differences, though statistically significant in some cases, are not large enough to be detected in the commercial classing of cotton '. Reynolds with Stansel [1935] failed to establish any definite relation between lint length and manure. Wood [1934] found that in the potash starved soils the lint was shorter, more irregular and contained a larger proportion of poorly thicked fibres. Crowther [1938] 'knew of no case where applying nitrogenous fertilizers had affected the quality of cotton grown under rainfall' in India. In the Sudan, however, under irrigation nitrogenous fertilizers delayed the maturity of the crop and consequent on the lateness the manured crop' tended to be inferior in quality to the unmanured crop'.

It can be gathered from the above that though a few workers have found some small influence of some manures, generally speaking, the effect is not large. The non-significant effect observed in the present case falls in a line with these findings.

CONCLUSIONS

The following deductions may be drawn from the present findings.

1. The micropylar end contains a very high percentage of mature fibres.

2. The maturity at the chalazal end varies considerably in the different strains. In some strains it is as high as about 90 per cent while in some as low as 30 per cent. In all cases, except one, the maturity for this region is statistically significantly less than that for any of the other regions.

3. In the other four regions studied, namely, right side, left side, region near the raphe and the back side, the differences among one another are generally not significant and the maturity is fairly high in all strains. In only four cottons, it is significantly less than that for the micropylar end.

4. Supply of better nutrition to the cotton plant does not appear to have produced any effect on the maturity in the field in which the soil is rich, while in the field with poor soil, supply of better nutriment is accompanied by improved maturity.

5. Differences in the nutrition supplied appear to have negligible influence on the fibre length, fibre weight per cm. and intrinsic fineness.

ACKNOWLEDGEMENTS

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REFERENCES

Armstrong, G. M. and Bennett, C. C. (1933). *J. agric. Res.* **47**, 467-74
Clegg, G. G. (1932). *J. Text. Inst.* **23**, T35-T54
Crowther, F. (1938). *Empire Cotton Grow. Rev. 3rd Conference on cotton growing problems : Report*, 1938, p. 53
Iyengar, R. L. N. (1932). *Proc. Indian Sci. Cong.* 1932.
Koshal, R. S. and Ahmad, N. (1932). *Indian Cent. Cotton Com. Tech. Lab., Tech. Bull. Series B*, No. **14**
Nelson, M. and Ware, J. O. (1932). *Arkansas Expt. Stn. Bull.* **273**
Peirce, F. T. and Lord, E (1939). *J. Text. Inst.* **30**/T 173-T 210
Reynolds, E. B. and Killough, D. T. (1933). *J. Amer. Soc. Agron.* **25**, 756-64
Reynolds, E. B. and Stansil, R. H. (1935) *J. Amer. Soc. Agron.* **27**, 408-11
Turner, A. J. (1929). *Indian Cent. Cotton Com., Tech. Lab., Tech. Bull. Series B, No.* **13**
Wood, R. C. (1934). *Empire Cotton Growing Review* **11**, 25

A NOTE ON THE VARIATION IN THE STANDARD FIBRE WEIGHT OF THE COTTON FIBRE IN RELATION TO ITS LENGTH

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IN a previous study by the writer and Turner [1930], it was found that the fibre weight per centimeter varied considerably in the different length grades of the fibres in strains of *G. hirsutum* but in those of *G. arboreum* the variation was not considerable. Similar non-variability was found for Sakel (*G. barbadense*), by Morton [1928] and by Balls [1928]. In another investigation, the writer [Iyengar, 1939] found that the mean ribbon-width and the swollen diameter of the fibre decreased with the increase in length in almost all cases. In the same work the maturity was found to vary in the different lengths, the trend of variation, however, being different in the different strains. As the fibre weight would be influenced by the maturity of the fibre, it was thought advisable to eliminate the influence of the maturity. This was done in the present study by calculating the standard fibre weight data. The results for the fibre weight per centimeter and the maturity percentage from which the standard fibre weight was calculated were taken from another paper [Iyengar, 1941]. For the sake of easy reference they are given in Table II. The formula* of Peirce and Lord [1934] was employed to calculate the standard fibre weight. As some differences were observed between the values for the thin-walled and 'dead' fibres as obtained by the method described by Peirce and Lord [1934] and that given by the writer [Iyengar, 1939], the standard fibre weight was calculated according to both methods. The differences between them are, however, seen to be not considerable.

The results are given in Table I.

It will be seen that in all the three cottons the standard fibre weight systematically increases with decrease in length. In Co 1 and Co 2 the differences between the extreme values of the observed fibre weight per centimeter were 17·2 per cent and 20·2 per cent respectively. These were reduced to 14·0 per cent and 12·2 per cent respectively in the standard fibre weight. In the case of K 546, however, it increased from 9·4 per cent to 22·6 per cent. In other words, it means that in the first two cottons the variations in the maturity showed exaggerated variations in the fineness among the different length grades, while in the third they had a masking effect.

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* From a discussion at Technological Assistants' Conference (1940) at the Matunga Laboratory where work on this subject is in progress, it was learnt that the old formula was more suited to Indian cottons than the new one [Peirce and Lord, 1939].

TABLE I

Observed and standard fibre weights

Group length in 1/8 in.	Co 1*			Co 2*			K 546*		
	Observed	Standard: Peirce & Lord	Standard: Iyengar	Observed	Standard: Peirce & Lord	Standard: Iyengar	Observed	Standard: Peirce & Lord	Standard: Iyengar
10	1·85	1·90	1·85	1·80	2·08	2·02	2·10	2·01	2·00
9	1·93	1·98	1·94	1·93	2·12	2·05	2·35	2·18	2·17
8	2·02	2·06	2·00	2·05	2·19	2·13	2·40	2·28	2·26
7	2·12	2·11	2·07	2·15	2·27	2·21	2·41	2·40	2·36
6	2·20	2·16	2·13	2·21	2·34	2·28	2·39	2·56	2·51
Difference between extremes as per cent of mean	17·2	12·6	14·0	20·2	11·7	12·2	9·4	24·1	22·6

* Co 1 and Co 2 belong to *G. hirsutum* Linn., K 546 belongs to *G. arboreum* var *neglectum* forma *indica* H. & G.

But when they were expressed in terms of standard fibre weight, where the differences in the maturity were eliminated, all the three strains showed increases with the decrease in length of the fibre. Such a finding is in conformity with the conclusions arrived at from the data of width measurements [Iyengar, 1939].

The above studies demonstrate clearly that the presence of immature fibres has been the cause of the differential behaviour observed in different cottons, in the relationship between the fibre weight and lint length grades.

The foregoing findings lead one to suspect whether the maturity factor may not be the cause for non-variability observed in *G. arboreum* by Iyenger and Turner [1930] and in Sakel both by Morton [1928] and by Balls [1928]. Unfortunately the maturity figures for the different length-grades are not available for these cottons.

TABLE II

Property	Name of strain	No. of determinations	Group length classes in inches: 10/8	9/8	8/8	7/8	6/8	Critical difference ($P = 0·05$)
ibre weight per cm (in 10^{-6} gm.)	Co 1 Co 2 K 546	72 72 56	1·85 1·80 2·19	1·93 1·93 2·35	2·02 2·05 2·40	2·12 2·15 2·41	2·20 2·21 2·39	0·0252 0·0286 0·0350
ature fibres (per cent)	Co 1 Co 2 K 546	90 24 28	64·7 47·8 91·9	65·0 54·1 88·1	66·2 59·1 83·5	71·8 62·0 74·2	74·9 62·5 63·3	3·6 10·3 5·2
mmature fibres (per cent)	Co 1 Co 2 K 546	90 24 28	15·1 33·4 3·8	15·9 25·0 4·6	14·8 21·2 8·0	12·0 20·2 14·6	11·0 21·6 25·2	2·5 8·7 5·9
alf mature fibres (per cent)	Co 1 Co 2 K 546	90 24 28	20·2 18·8 4·4	19·1 21·0 7·3	19·1 19·7 8·5	16·2 17·8 11·2	14·1 15·8 11·4	2·9 3·5 3·8

For the analysis of variance of the results reference may be made to the work of Iyengar [1941].

REFERENCES

Balls, W. L. (1928). *Studies of quality in cotton* : Macmillan & Co. p. 154

Iyengar, R. L. N. (1939). *Indian J. agric. Sci.* **9**, 305-29

———————— (1941). *Indian J. agric. Sci.* **11**, 703

Iyengar R. L. N. and Turner A. J. (1930). *Indian Cent. Cott. Com. Tech. Lab., Tech. Bull. Ser. B.* No. 7

Morton, W. E. (1928). *J. Text. Inst.* **19**, T 550

Peirce, F. T. and Lord, E. (1934). *Emp. Cott. Growing Rev., Second Conference Report, 1934*, 223-44

———————— (1939). *J. Text. Inst.* **30**, T173-T210

STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB

XI. EFFECT OF MIXED CROPPING ON THE INCIDENCE OF THE DISEASE

BY

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(With Plates LIX and LX and two text-figures)

THE growing of cotton mixed with another crop has been practised for long in India and other tropical countries. In the Punjab a fodder or a pulse crop is usually sown with cotton. In the Tanganyika territory this has been a native method of introducing simultaneous rotation [Robertson, 1938].

Some preliminary observations on the effect of mixed cropping on the incidence of cotton root-rot disease in the Punjab have already been recorded [Vasudeva and Ashraf, 1939]. It has been shown that the incidence of the disease is significantly reduced in plots in which cotton is sown in mixture with sorghum. Further experiments have now been carried out on similar lines, and the results are presented in this paper.

EXPERIMENTAL

The experiments reported here were conducted at Lyallpur on land which was heavily and uniformly infected with the disease and whose previous history was known from observations made for a number of years. Some experiments were also carried out at the British Cotton Growing Association Farm, Khanewal, in order to confirm the results obtained at Lyallpur.

Cotton was sown in May, which is the optimum time for the occurrence of the disease so that all the necessary conditions were provided for a vigorous attack of the disease in order to obtain reliable data.

A. *Effect of inter-cropping cotton with sorghum*

A plot of land heavily and uniformly infected with the disease was divided into 20 sub-plots 45ft. × 18ft. and sown with *G. indicum* variety Mollisoni 39, an indigenous type, on 16 May 1939. Six rows of cotton were sown in each plot at a distance of $2\frac{1}{2}$ feet apart. Sorghum variety J 20 was sown by broadcasting the same day in between the cotton lines in 16 plots. A border of 2 ft. was also sown with sorghum around the cotton crop so that the plot was surrounded by it on all the four sides. The remaining four plots were sown with cotton only to serve as controls.

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TABLE

Root-rot mortality in mixed

Week ending	Un-cropped area						Cotton				
	8 A.M.			5 P.M.			8 A.M.			5	
	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature
(1939)	(°F.)	(°F.)		(°F.)	(°F.)		(°F.)	(°F.)		(°F.)	(°F.)
20 June	...	...	...	...	...	...	...	...	...	...	...
26 June	88·0	92·0	71·8	99·7	97·0	40·3	89·6	89·7	57·1	101·4	94·0
3 July	85·1	90·0	78·1	96·4	94·6	45·3	88·8	88·3	74·4	95·5	92·7
10 July	88·7	94·8	61·4	103·4	100·0	34·8	87·8	92·6	62·1	100·6	98·0
17 July	92·3	96·0	63·8	103·1	101·8	40·6	90·2	93·8	67·6	102·7	98·3
24 July	89·6	89·0	61·8	102·6	99·3	40·1	89·0	90·1	63·8	100·6	93·8
31 July	90·5	95·8	57·7	100·8	100·8	38·9	89·8	92·2	60·9	99·8	96·7
7 Aug.	83·0	91·3	76·6	95·4	95·8	53·9	82·6	86·0	81·0	94·0	90·1
14 Aug.	89·4	92·7	56·3	102·8	100·0	32·1	86·8	88·1	67·8	99·7	95·0
21 Aug.	93·8	96·7	46·7	103·6	101·7	32·2	89·0	87·7	59·8	98·0	91·3
30 Aug.	...	...	...	...	...	...	...	...	...	...	...
4 Sept.	...	...	...	...	...	...	...	...	...	...	...
11 Sept.	...	...	...	...	...	...	...	...	...	...	...
18 Sept.	...	...	...	...	...	...	...	...	...	...	...
25 Sept.	...	...	...	...	...	...	...	...	...	...	...
2 Oct.	...	...	...	...	...	...	...	...	...	...	...

I

and pure cotton plots

only		Cotton + sorghum									
P.M.		8 A.M.			5 P.M.			Per cent mortality			
								Date of removal of sorghum			
Av. per cent humidity	Per cent mortality	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature	Av. per cent humidity	20 July	30 July	10 August	16 August
		(°F.)	(°F.)		(°F.)	(°F.)					
...	7·67	...	...	...	...	...	...	0·66	1·66	2·92	0·83
38·7	12·47	87·1	88·8	67·1	97·0	90·6	56·0	1·25	0·83	1·63	0·34
48·8	10·84	83·8	87·0	81·8	91·9	88·5	61·7	0·00	0·08	0·35	0·16
42·1	4·84	85·4	88·3	74·7	98·4	90·1	51·0	0·08	0·00	0·08	0·08
51·2	10·47	88·8	91·0	77·2	101·0	93·4	59·1	0·00*	0·00	0·08	0·00
51·1	12·1	87·7	88·1	71·3	96·4	90·1	60·8	0·00	0·00*	0·00	0·00
41·7	5·72	89·8	89·7	63·6	97·7	93·3	50·4	0·00	0·00	0·00	0·00
61·8	12·47	82·0	85·6	86·1	93·6	89·4	62·7	0·00	0·00	0·00*	0·00
40·8	3·21	85·8	86·3	76·0	96·6	91·0	53·2	0·08	0·00	0·00	0·00*
46·8	2·12	87·0	86·0	67·0	98·3	89·0	47·8	2·49	0·08	0·26	0·00
...	1·78	...	...	...	...	...	...	3·35	1·65	0·00	0·00
...	1·2	...	...	...	...	...	...	8·23	3·22	2·14	0·00
...	2·23	...	...	...	...	...	...	6·71	7·02	5·9	0·09
...	0·2	...	...	...	...	...	...	1·68	3·35	4·9	0·8
...	0·2	...	...	...	...	...	...	0·34	0·92	1·2	0·3
...	0·0	...	...	...	...	...	...	0·34	0·23	0·34	0·2

*Stage of removal of sorghum so that the crop was no longer mixed.

It is obvious that close planting of sorghum with cotton will adversely affect the growth of cotton plants. With a view, however, to save the cotton crop from this adverse effect on growth, the sorghum plants must not be left standing in the field longer than is absolutely necessary to reduce the incidence of the disease to the lowest possible limit. In order to find the most advantageous time for the removal of sorghum for this purpose the 16 subplots sown to the mixed crop were divided into four lots of four each and sorghum was removed on four different dates, i.e. on 20 July, 30 July, 10 August and 16 August, respectively.

The experiment was conducted on the randomized system. Counts of mortality due to root-rot were made at weekly intervals both in the mixed and pure cotton plots. Air temperature, soil temperature at 30 cm. depth and humidity records were taken twice a day, i.e. at 8 A.M. and 5 P.M. inside the mixed as well as control plots. Temperature and humidity records were also taken in an uncropped piece of land adjacent to the experimental area. The average per cent mortality from week to week in each set of four plots and temperature and humidity inside mixed and pure cotton plots is shown in Table I. Percentage mortality in each set of plots at the end of the root-rot season before and after removal of sorghum is shown in Table II. Plate LIX fig. 1 shows a plot of cotton soon after removal of sorghum and a check pure cotton plot. Plate LIX, fig. 2, shows control and a mixed plot from which sorghum was removed on 10 August at fruiting stage.

The results recorded in Table I show that :—

1. Mortality in the mixed crop is lower than in pure cotton throughout.

2. About three weeks after removal of sorghum the disease made a fresh start. The highest total mortality occurred in the first lot from which sorghum was removed on 20 July and the least mortality was in the fourth lot from which sorghum was removed on 16 August.

3. Soil temperature is lower in the mixed crop throughout.

4 Air temperature on the whole is lower in the mixed crop.

5. Humidity is higher in the mixed crop.

6. Soil and air temperatures are throughout lower in the cotton than in the un-cropped area.

7. Humidity tends to be higher in the cotton than in un-cropped area.

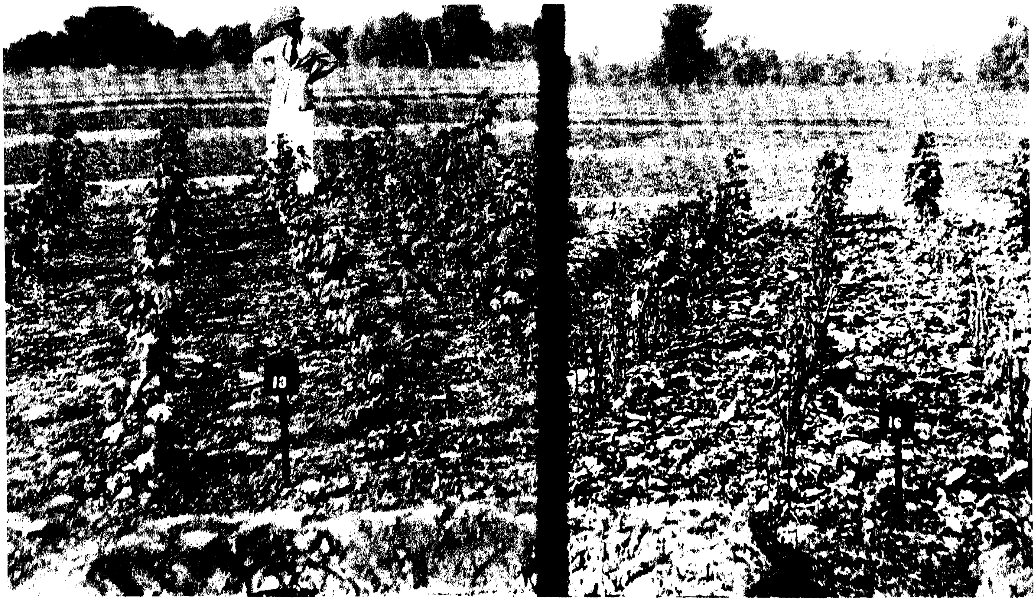
The data given in Table II bring out the following points of interest :—

1. Mortality before removal of sorghum is appreciably low in all the four groups.

2. Mortality after removal of sorghum is highest in the first group and lowest in the fourth group.

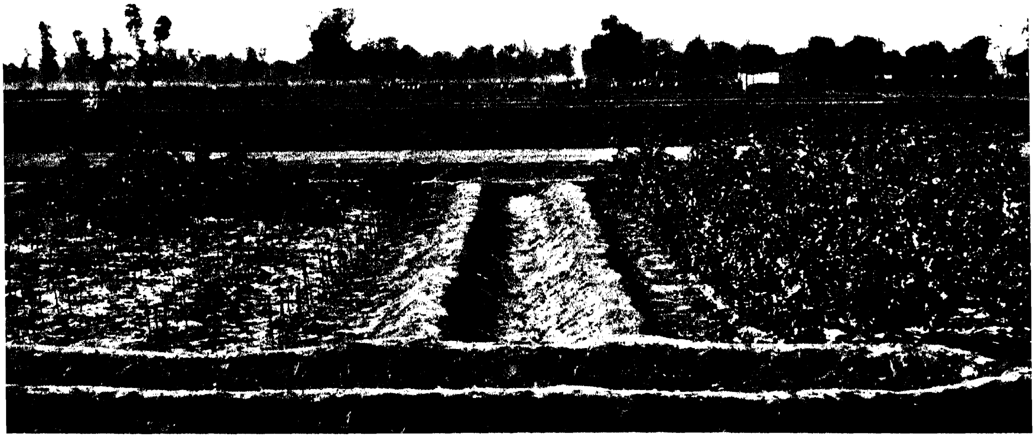
3. The incidence of the disease is reduced to the minimum in the fourth group, i.e. 3 per cent against 69 per cent in control, showing thereby that the best time for removal of sorghum is the middle of August.

It may, however, be mentioned that the plants of the fourth group remained rather small in size and their growth was poor, whereas those of the first and second group almost recovered from the adverse effect of the sorghum crop and their growth proceeded normally afterwards.



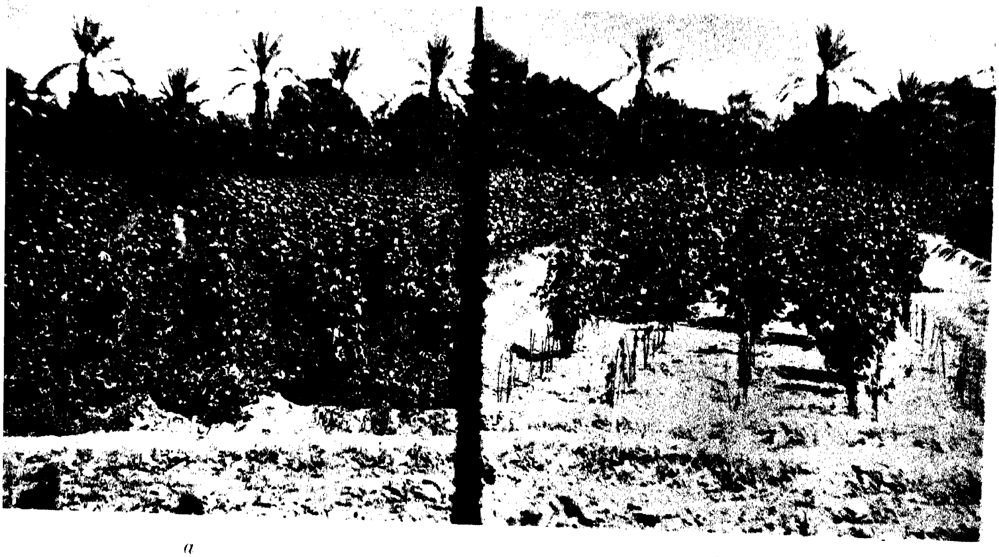
(*a*) (*b*)

FIG. 1. (*a*) Plot of cotton soon after removal of sorghum ; (*b*) Check pure cotton plot (Sticks indicate the positions of plants killed)



(*a*) (*b*)

FIG. 2. (*a*) Control pure cotton plot ; (*b*) Mixed plot from which sorghum has been removed on 10 August at fruiting stage



IG. 1. (*a*) Plot of cotton inter-cropped with *moth* (*Phaseolus aconitifolius*); (*b*) Pure cotton plot

FIG. 2. The mixed plot with *moth* removed

TABLE II

Incidence of the disease in relation to the time of removal of sorghum

Set No.	Date of removal of sorghum (1939)	Average per cent mortality		Total per cent mortality
		Before removal of sorghum	After removal of sorghum	
I	20 July . . .	1·99	22·30	23·80
II	30 July . . .	2·50	17·00	18·70
III	10 August . . .	5·00	15·70	20·00
IV	16 August . . .	1·40	1·65	3·40
V	Pure cotton control .	..	..	68·50

B. *Effect of inter-cropping cotton with* moth *and small millets*

The effect of mixed cropping with *moth* (*Phaseolus aconitifolius*), *swank* (*Panicum colonum*) and *kangni* (*Setaria italica*) was tested in a piece of land heavily infected with the disease. *Desi* cotton var. (Mollisoni 39) was sown on 14 May in rows 2½ feet apart. Six rows of cotton were sown in each plot and in between the cotton rows *moth*, *swank* or *kangni* was sown on the same day ; also a border of the same crop 2 ft. in width was sown around the cotton. Three plots were sown with each of the mixtures and three plots were put under pure cotton as checks. The plots were randmomized. Root-rot mortality counts were taken at weekly intervals. Soil temperature, air temperature and humidity were recorded inside the mixed and pure cotton plots at 8 A.M. and 5 P.M. *Moth*, *swank* and *kangni* were removed from cotton plots on 18 August. Results of this experiment are given in Table III. Fig. 1 shows the effect of mixed cropping on the incidence of the disease.

The general conclusions deduced from the data set out in Table III are as follows :—

1. Root-rot mortality in cotton + *moth* is lower than in pure cotton. The differences are highly significant, t being 6·03. For a series of 10 observations a value of t equal to 2·23 is just significant [Fisher, 1925]. Soil temperatures and air temperatures are lower in the mixed crop but humidity is higher than in pure cotton.

2. In cotton + *swank* mortality due to root-rot is lower throughout except in the first week ($t = 3·32$) but there are no regular differences in soil and air temperatures. Humidity tends to be higher in the mixed crop but the differences are not marked as these vary from —0·2 to +4·7 in the morning and from —2·7 to +3·3 in the evening.

TABLE

Effect of inter-cropping cotton with moth *and*

Week ending	Cotton only							Cotton + *swank* (*Panicum*					
	8 A.M.			5 P.M.				8 A.M.			5 P.M.		
	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature	Av. per cent humidity	Per cent mortality	Av. air temperature	Av. soil temperature	Av. per cent humidity.	Av. air temperature	Av. soil temperature	Av. per cent humidity
(1939)	(°F.)	(°F.)		(°F.)	(°F.)			(°F.)	[(°F).		(°F.)	(°F.)	
20 June . .	...	...	...	...	...	...	12·5	...	...	...	...	...	...
26 June . .	89·8	90·4	57·2	99·5	94·5	48·2	6·84	89·6	89·7	58·1	98·7	94·1	48·8
3 July . .	82·3	85·8	80·0	92·6	89·5	55·7	8·19	81·8	86·1	83·3	93·0	89·8	57·8
10 July . .	88·1	90·0	66·4	97·8	95·6	46·4	4·45	88·1	88·7	70·8	99·7	94·4	46·4
17 July . .	89·7	89·5	72·4	95·1	92·6	57·2	11·42	89·7	89·0	76·1	98·1	91·8	57·2
24 July . .	88·0	88·7	66·8	96·6	91·7	57·6	8·15	87·7	88·7	71·5	97·0	92·0	59·6
31 July . .	88·7	91·3	63·8	97·0	94·2	47·7	4·58	89·2	90·2	66·1	98·2	94·5	51·0
7 Aug. . .	82·4	84·6	79·8	90·6	88·3	67·6	9·9	83·0	85·7	83·1	93·0	90·6	64·9
14 Aug. . .	87·3	87·0	62·3	95·1	90·8	50·5	4·0	87·8	87·3	70·3	89·0	92·4	50·1
21 Aug. . .	88·3	87·0	59·5	94·7	88·7	51·0	1·73	90·3	88·0	59·3	97·7	92·0	51·8

III

small millets on the incidence of root-rot disease

colonum	Cotton + *kangni* (*Setaria italica*)							Cotton + *moth* (*Phaseolus aconitifolius*)						
	8 A.M.			5 P.M.				8 A.M.			5 P.M.			
Per cent mortality	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature	Av. percent humidity	Per cent mortality	Av. air temperature	Av. soil temperature	Av. per cent humidity	Av. air temperature	Av. soil temperature	Av. per cent humidity	Per cent mortality
	(°F.)	(°F.)		(°F.)	(°F.)			(°F.)	(°F.)		(°F.)	(°F.)		
13·66	...	...	...	...	...	...	11·0	...	...	...	...	...	...	5·52
6·56	89·7	89·8	69·3	95·8	93·7	49·4	11·5	89·2	91·0	66·6	98·8	94·1	45·9	4·43
6·81	82·1	86·1	82·4	91·3	88·3	63·6	15·35	80·1	84·3	85·7	89·4	86·3	68·3	1·48
1·77	85·6	88·0	73·0	96·3	91·0	54·8	3·87	84·3	84·3	82·2	93·0	86·4	63·4	0·00
0·45	88·7	87·7	79·0	94·8	90·1	65·2	0·26	85·8	84·8	85·1	92·3	87·1	71·1	0·00
0·00	87·6	87·4	73·8	94·8	89·8	64·6	0·27	86·0	85·3	82·1	92·6	87·6	69·3	0·00
0·22	88·5	89·2	66·4	97·2	92·3	51·6	0·00	86·0	86·0	77·7	91·8	88·5	64·4	0·00
0·00	82·8	85·3	83·3	91·6	88·6	71·6	0·00	81·0	63·3	88·8	89·0	86·1	79·7	0·00
0·00	87·7	87·1	68·8	93·3	91·4	53·4	0·00	85·3	84·7	77·1	91·8	88·0	69·5	0·00
...	89·7	88·0	62·1	96·0	90·7	56·7	0·00	86·0	84·7	76·8	91·3	87·3	67·2	0·00

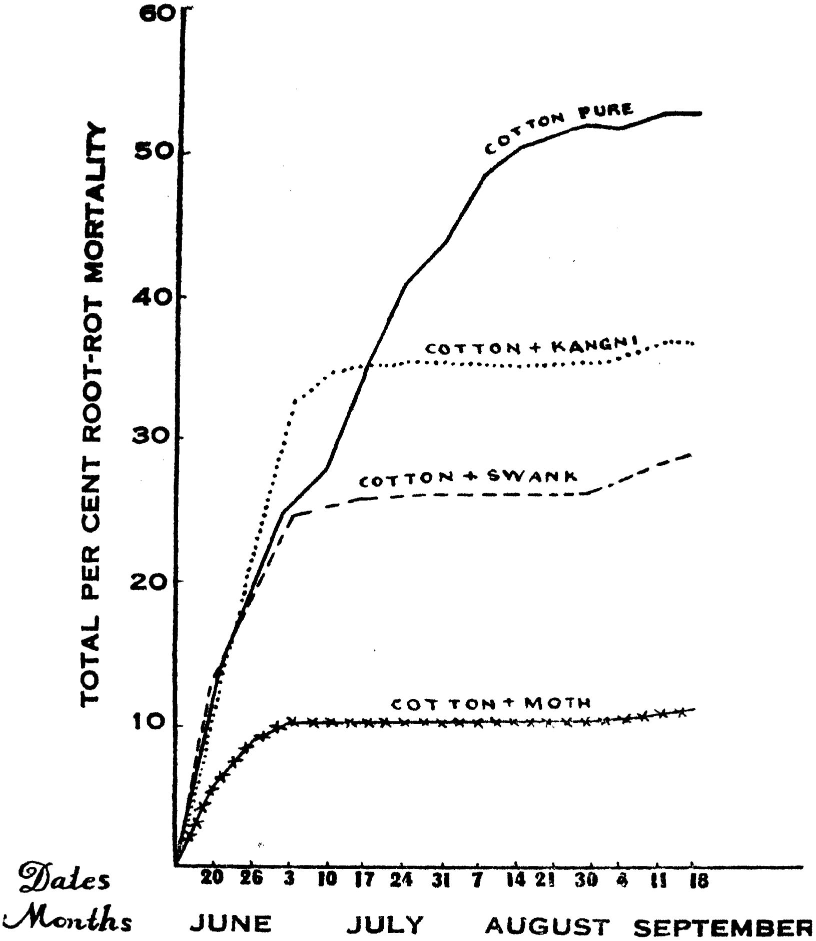


FIG. 1. Effect of mixed cropping on root-rot mortality

3. In cotton + *kangni* root-rot mortality is high in the first three weeks but after 3 July 1939 there is a marked decline in the death rate. *Kangni* plants were very small in size during the first few weeks and did not serve as a cover to cotton plants. The differences in mortality are, however, insignificant, *t* being 1·58. There are no regular differences in soil and air temperatures but humidity is higher in the mixed crop throughout. The differences in the mornings vary from 2·4 to 12·1 and 1·2 to 8·4 in the evenings.

It might, however, be mentioned that germination and growth of *swank* and *kangni* were very poor. Germination was delayed on account of dryness of the weather. Both the crops therefore did not materially help in reducing soil and air temperatures in the mixed crop. All the same, it is indicated that *swank* and *kangni* tend to reduce root-rot mortality though the results are not significant in the case of the latter crop. It is probable that if the crop had grown normally, the incidence of the disease would have been further reduced in both the cases.

Where *moth* was sown in between the cotton rows, root-rot mortality was observed only during the first couple of weeks in the spots where *moth* had not yet grown properly. *Moth* neither shaded nor greatly affected the growth of cotton plants. Plate LX, fig. 1 shows a plot of cotton intercropped with *moth* and a pure cotton check plot. Plate LX, fig. 2 shows the mixed plot with *moth* removed.

An experiment was conducted in 1940-41 in order to find the most suitable time for the removal of *moth*. *Desi* cotton variety Mollisoni 39 was sown in 20 heavily diseased plots on 16 May 1940. *Moth* was inter-cropped in 16 plots. The remaining four pure cotton plots served as controls. The experiment was conducted on the randomized system. Mortality, temperature and humidity records were taken as usual. *Moth* was removed from four plots at a time on different dates. The results of the experiment are summed up in Table IV.

TABLE IV

Incidence of the disease in relation to the time of removal of moth

Set No.	Date of removal of *moth* (1940)	Average per cent mortality		Total per cent mortality	Yield per acre	
		Before removal of *moth*	After removal of *moth*		Green *moth* Md. Sr. Ch.	Seed cotton Md. Sr. Ch.
I	1 Aug.	0·86	0·00	0·86	209 22 0	12 6 12
II	15 Aug.	0·67	0·00	0·67	202 5 0	10 20 12
III	30 Aug.	0·45	0·00	0·45	167 19 0	8 30 10
IV	22 Oct.	1·1	0·00	1·1	74 34 12	7 6 11
V	Pure cotton	..	..	52·51	..	10 16 10

The results show that total mortality in the mixed plots is almost negligible, i.e. about 0·5-1 per cent as against 53 per cent in the pure cotton plots. They also show that after the removal of *moth* on different dates no deaths occurred due to root-rot, indicating thereby that in order to reduce mortality to an appreciable degree it is quite safe to remove *moth* as early as the first of August.

Yield of green *moth* in different cuttings varied from 209½ mds. to 75 mds. per acre. Yield was much reduced in the last cutting because the fodder had partly dried up. Yield of seed cotton in the first lot tends to be higher than pure cotton control plots, but the difference is not significant. The yield from the second lot is almost the same as in the controls, whereas the yield of the second and third lots is lower than the controls. It might, however be mentioned that soil and air temperatures were lower in the mixed crop, whereas humidity was higher throughout.

At Lyallpur, in addition to *moth*, cowpea (*Vigna catiang*), *guara* (*Cyamopsis psoralioides*) and sorghum were also sown mixed with *desi* cotton variety Mollisoni 39 to test their effect on the incidence of the disease. The sowings were done on 17 May 1940 and the crops were removed on the 16 August. The results of the experiment are given in Table. V.

TABLE V

Effect of inter-cropping desi *cotton with different crops*

Treatment	Average per cent mortality (3 plots)	Yield per acre					
		Green inter-crop			Seed cotton		
		Md.	Sr.	Ch.	Md.	Sr.	Ch.
Cotton + cowpea	10·05	311	15	11	7	24	10
Cotton + *guara*	2·40	588	23	2	6	33	7
Cotton + sorghum	0·87	357	6	10	3	29	1
Pure cotton	50·89		..		10	21	5

Plants of all the crops inter-cropped in between the cotton rows grew tall and shaded the cotton plants, resulting in their poor growth and reduced yield. Soil and air temperatures were lower in the mixed crop, whereas humidity was higher than in the pure cotton check plots.

Four more experiments were carried out in 1940-41, both at Lyallpur and B. C. G. A. Farm, Khanewal, to test the effect of mixed cropping with *moth* as a measure to control the disease.

In two experiments American cotton (*G. hirsutum*) was inter-cropped with *moth*. One experiment was laid out at Lyallpur and the other at Khanewal. Another set of similar experiments was laid out in which *desi* cotton (*G. indicum*) was intercropped with *moth*.

All these experiments were conducted on randomized system in heavily infected plots and the sowings were done in the middle of May. Soil and air temperatures and humidity records were taken only at Lyallpur. These confirmed the previous findings that the temperature is lower in the mixed plots, whereas humidity is higher.

The results of all the four experiments are summed up in Table VI. Fig. 2 shows the effect of inter-cropping American cotton with *moth* on the incidence of the disease (var. LSS).

TABLE VI

Effect of inter-cropping desi *and American cottons with* moth *on the incidence of the disease and yield of seed cotton*

Station	Treatment	Variety	Av. per cent mortality	Av. yield per acre	
				Green *moth*	Seed cotton
				Md. Sr. Ch.	Md. Sr. Ch.
Lyallpur .	American cotton + *moth*	LSS .	0·92	190 6 15	15 15 9
	Pure cotton (control)	LSS .	63·09	. .	4 25 2
	Difference of means per plot				5·37 Sr.
	S. E. of the difference per plot				0·47
	t				11·40
Khanewal .	American cotton + *moth*	KT 25	2·98	220 35 11	12 24 5
	Pure cotton (control)	KT 25	45·92	. .	4 13 0
	Difference of means per plot				11·20 Sr.
	S.E. of the difference per plot				0·92
	t				12·20
Lyallpur .	*Desi* cotton + *moth* .	Mollisoni 39	2·42	222 23 2	14 25 8
	Pure cotton (Control)	Mollisoni 39	55·35	. .	11 5 6
	Difference of means per plot				1·74 Sr.
	S.E. of the difference per plot				1·56
	t				1·12
Khanewal .	*Desi* cotton + *moth* .	Mollisoni 39	1·81	220 35 11	15 33 3
	Pure cotton (control)	Mollisoni 39	52·22	.	9 8 2
	Difference of means per plot				9·00 Sr.
	S.E. of the difference per plot				0·71
	t				12·67

The results show that root-rot mortality is markedly reduced in the mixed crop and also yield of American seed cotton is higher in the mixed plots both at Lyallpur and Khanewal than in the pure cotton check plots. The differences are highly significant.

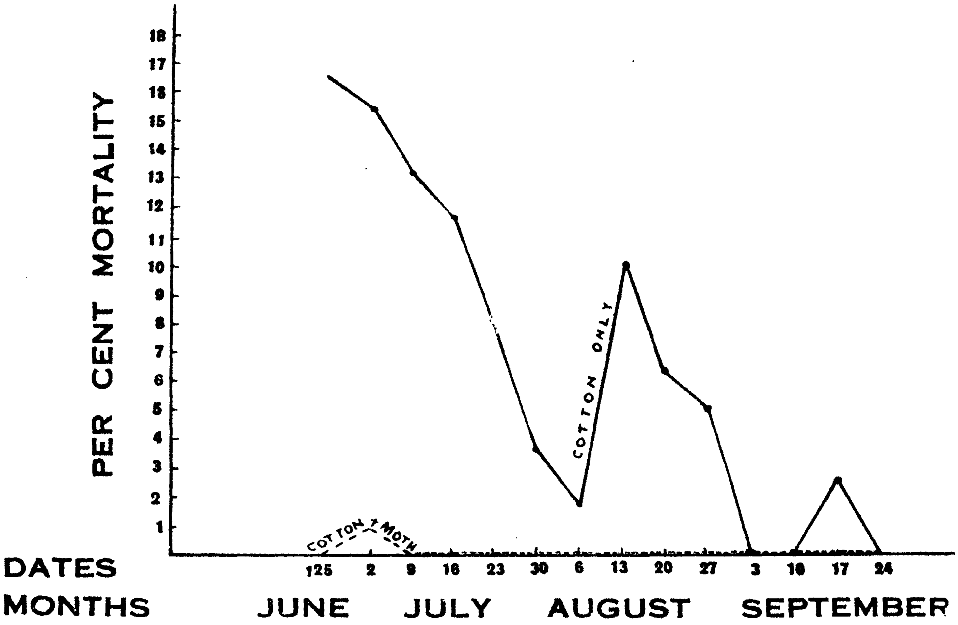


Fig 2. Effect of inter-cropping cotton with *moth* on the incidence of the disease (var. LSS), Lyallpur, 1940-41

In the case of *desi* cotton the yield is higher in the mixed plots both at Khanewal and at Lyallpur, but the results are significant only in the former case. It appears that the growth of plants and the yield of seed cotton is adversely affected in the case of *Desi* cotton when it is sown mixed with *moth*. Sufficient data are not yet available to explain this difference between *desi* and American cottons. This may either be due to the habit of the plant, or to the fact that American cotton gets sufficient time to make good the loss due to inter-cropping as it matures about 1½ months later than the *desi* cotton.

Later on it may be made possible by certain modifications, such as adjustment of sowing time or time of removal of inter-crop to get remunerative returns even from *desi* cottons. It should be remembered that an additional income accrues from the fodder crop raised from the mixed plots.

Further work is required to investigate the causes of reduction in mortality in cotton sown in mixture with various crops. Temperature may be an important factor, but it is likely that some other factor also comes into play which helps in reducing the incidence of the disease, as in the case of *swank* where the temperature was not materially affected in the mixed crop but the incidence of the disease was reduced.

Summary

1. When cotton is inter-cropped with sorghum or *moth* (*Phaseolus aconitifolius*) the incidence of the root-rot disease is significantly reduced. Soil and air temperatures are lower within the mixed crop but humidity is higher than in the pure cotton plots.

2. Two varieties of American cottons when sown in mixture with *moth* gave higher yields than the pure cotton.
3. Incidence of the disease is also reduced when cotton is sown in mixture with certain other crops.

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REFERENCES

Fisher, R.A. (1925). *Statistical methods for research workers* : Edinburgh, Oliver and Boyd

Robertson, J. (1938). *Empire Cotton Growing Corporation, Report of third Conference*, pp. 28-9

Vasudeva, R. Sahai and Mohd. Ashraf. (1939). *Indian J. agric. Sci.* **9**, 595—608

PINK DISEASE OF ORANGE TREES IN THE CENTRAL PROVINCES

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(With Plates LXI–LXIII)

PINK disease caused by *Corticium salmonicolor* B. & Br. is widespread both as regards its geographical distribution and its range of hosts. In the Central Provinces, however, this disease causes serious damage only to one host, viz. orange trees (*Citrus aurantium*) and that too only in a restricted locality. Orange cultivation is spread over several districts in this province but so far the disease has been known to occur only in Balaghat, Betul, Jubbulpore and Ramtek (Nagpur district). In Jubbulpore and Ramtek only stray cases of infection have been recorded. In Betul this disease in 1939 was found on a number of orange trees but last year the disease was not reported to have done any further damage. In Balaghat the disease is usually in an epidemic form and is a serious threat to the further expansion of orange orchards in this district.

SYMPTOMS

The disease does most damage during the wet season. The presence of the disease is readily noticed when the leaves of a branch wilt, turn yellow and drop. If the diseased branch is examined, the cause of its dying from the top and of the defoliation or wilting of the leaves is evident ; the affected part of the branch is either covered with a fine silvery white film named 'spinnengewebe' by Rant [1911] or is studded with white or pink coloured raised pustules of the size of a pin head, or it is covered with pinkish coloured pockmarks caused by the flaking off of scales of the bark giving this part of the branch a general pinkish appearance. In the case of thin branches and twigs the bark when badly diseased is in shreds and the wood is exposed. In some cases the infection can only be detected by the presence of cankers on the twigs and small branches (Plate LXI, fig. 1).

The secondary effects of the disease on a branch are (1) shredding of the bark, (2) scaling or exfoliating of the bark, and (3) gumming and development of cankers.

As a result of the development of pustules the bark becomes dry, the thin-walled cells are destroyed, and the bark is torn into ribbons or fibrous shreds ; this happens especially in the case of infected branches which are not thicker than one's finger. Usually this tearing up of the bark is not associated with the presence of the spinnengewebe hyphae.

In some cases small thin pieces of bark of the branches exfoliate. The result is that small shallow depressions or pits or pock marks are formed on the surface ; when fresh they are distinctly pink or pale rose coloured, and

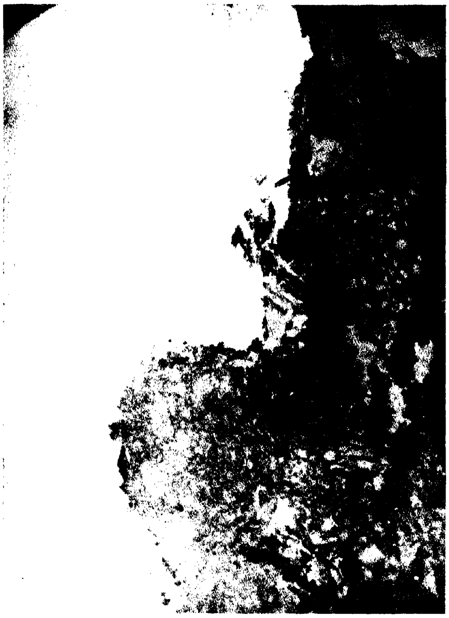
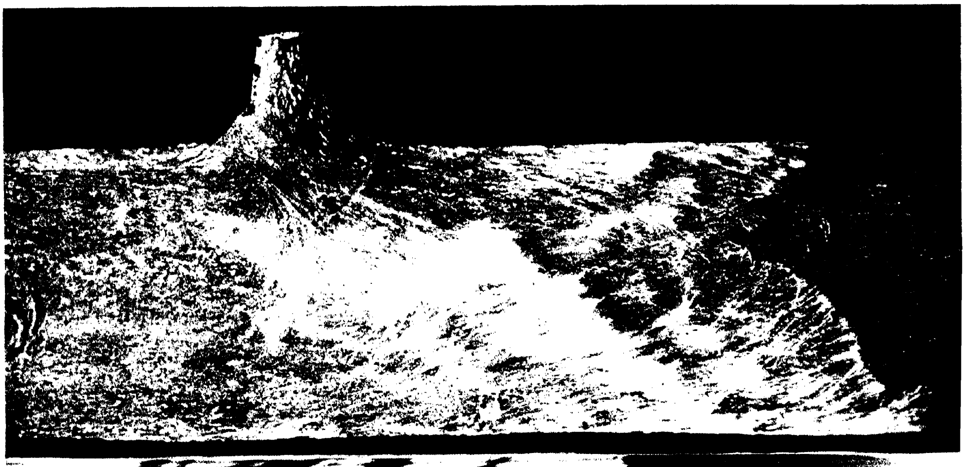


FIG. 3. A photo-micrograph of a deep seated pustule bursting through the bark. Note the presence of host cells in the pustule



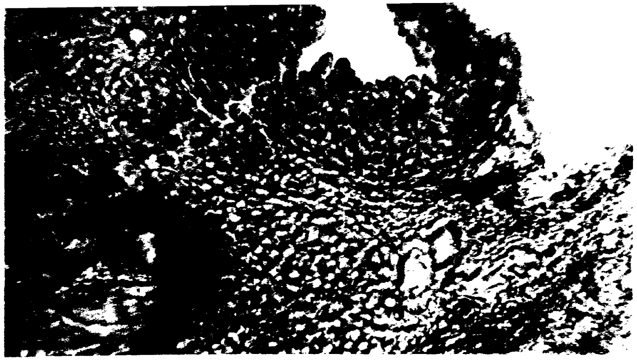


Fig. 1. A photo-micrograph of a *Necator* pustule with spores

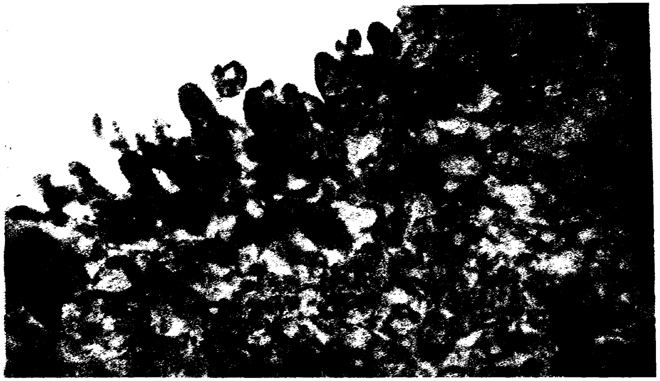


Fig. 2. A photo-micrograph of a part of the basidial stage, showing basidia formed in a row from the hymenial layer

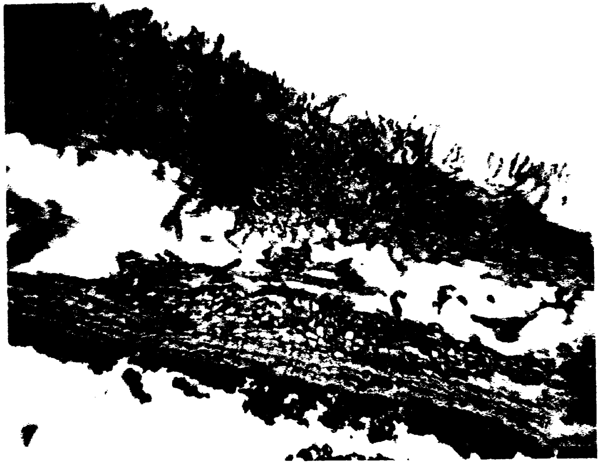
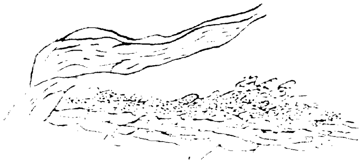


Fig. 3. A photo-micrograph showing a section of the basidial stage; the basidia are scattered



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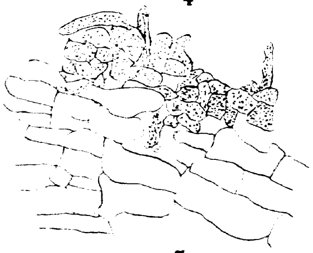

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Fig. 4. A semi-diagrammatic drawing of a section through a pit in the bark showing the remnants of a pustule over the host tissues (× 65)

Fig. 5. An enlarged view of a part of the above section (× 600)

when they are numerous the affected limb has distinctly a general pink coloured appearance. With age the colour of the pits changes to dirty white or pale brown. The exfoliating of the bark may at times be accompanied with slight exudation of gum. The scaling of the bark takes place where pustules had developed. If sections through the pits are examined under the microscope, a layer of pseudoparenchymatous fungus tissue or scattered, short, roundish or angular fungus cells are readily seen ; they are the basal remnants of the pustules which have dropped off with the exfoliating bark (Plate LXII, figs. 4, 5).

Occasionally, vertical small cracks are formed on the diseased bark from which drops of gum exude. When the development of gum pockets is confined to tissues outside the cambium, new meristematic tissue is developed below the gum pocket which later is sealed off. But when the gum pocket destroys the cambium the bark above the affected part sloughs off, exposing the discoloured wood ; a canker is formed, which may be a large gaping wound or may be very small and not readily noticeable. In the tissues of the callus formed round the wound are sometimes seen inter-cellular strands of hyphae or small aggregates of fungus cells resembling a stroma. These inter-cellular hyphae may very probably be the dormant mycelium of *Corticium salmonicolor* ; the stromatic aggregates are similar to the stroma of the pustules described above.

DESCRIPTION OF THE FUNGUS

The spinnengewebe form is at first silvery white in colour with feathery or cottony margins ; as the film extends up and down the limb, zones of feathery margins are distinctly visible (Plate LXI, fig. 2). This is specially noticeable when the affected limb is thick ; when the diseased twig is thin the margins are not conspicuously feathery. At a later stage the silvery white colour of the film changes to a general pink colour, except at the margins which are still feathery and white. With age the spinnengewebe film becomes dirty drab coloured. In the dry weather there are no externally visible signs of this film ; but under the microscope remnants of the hyphae can be seen in the crevices and folds of the bark as roundish or angular short cells.

The spinnengewebe form at first consists of a smooth mycelial felt on which at a later stage are seen white cushion-like growths or pustules, which are scattered or in linear rows. This mycelial felt is composed of long strands of hyaline thin-walled, sparsely-septate hyphae, 7-15 μ broad, running parallel to each other ; their branches interlace together ; no clamp connections have been observed. These hyphae grow chiefly superficially on the bark ; they are seen to enter the bark tissues only through a crack in the bark (Plate LXIII, fig. 9), or through the thin-walled cells of a lenticel. When hyphae are over a lenticel or the broken tissues of the bark they lose their filmy character and form a loose aggregate of thin-walled short cells (Plate LXIII, fig. 11).

The pustules or cushion-like growths are white or pink or orange-red or rose coloured. The white-coloured pustules are either wholly superficial on the bark or partly within the bark tissues ; but the pink or rose or orange-red coloured pustules are always wholly or partly embedded in the host tissues.

The white cushions are usually associated with the cobwebby or the spinnengewebe mycelium (Plate LXIII, fig. 2). The hyphae on the surface of the bark loosely aggregate together and form white cushion-like structures. The hyphae remain thin-walled, and the contents are neither granular nor different from those of the spinnengewebe mycelium, but the hyphae forming these cushions are distinctly narrower than those of the spinnengewebe form. These cushions are identical with the sterile white bodies described by Zimmermann [1901].

There is another type of white pustules. The hyphae of the cobwebby or spinnengewebe mycelium over a lenticel or over broken tissues of the bark or in a fold of the bark break up into short roundish or angular cells and form an aggregate of cells resembling a pseudoparenchymatous tissue (Plate LXI, fig. 4). These pustules may remain superficial or they may develop hyphae which may penetrate the host tissues where they are broken, or through the thin-walled cells of lenticels. At first the hyphae are intercellular ; the cell-walls of the host cells soon collapse under the pressure of the fungus tissue and the hyphae then become also intra-cellular. The hyphae from these pustules occasionally form aggregates under the epidermis or in the bark tissues or in the cortex (Plate LXIII, figs. 1 and 2).

The origin of the pink or orange-red pustules seems to be different from that of the white pustules described above. The hyphae or the pseudoparenchymatous aggregates inside the host tissues may lie dormant for a time, e.g. during the dry season. and under favourable conditions resume their growth and burst through the living tissues of the host.

The pustular forms of *Corticium salmonicolor* have been named by Rant [1910 and 1911] as Höckerchen form and 'Knobbeltjesize' form. According to him Höckerchen are the white pustules formed on the bark by a collection of thin-walled hyphae mostly on lenticels ; Zimmermann [1901] has also described these bodies though he has given no specific name to them ; they are superficially developed, white, round bodies consisting of thin-walled cells the contents of which are poor and therefore he does not consider them to be similar to sclerotia. According to Brooks and Sharples [1914] ' Pink disease frequently assumes the form of white or pale pink pustules arranged more or less in lines parallel with the branches ; this is the Höckerchen form of Rant'. Butler [1918] calls the pustular stage the nodular form which is white and which occurs chiefly in the lenticels. To Lee [1919] the sterile dirty white to pinkish coloured pustules ' which push through the hardened bark ' of *Citrus* ' appear to be the Höckerchen form described by Rant'. Subba Rao's description [1936] of the Höckerchen form is confused. It develops by some of the hyphae of the cobwebby mycelium aggregating ' here and there on the surface of the branch into small cushions of a pinkish or whitish colour' ; he further states that the hyphae form similar condensations or aggregates beneath the layer of cortical cells . His illustration No. 4, which is similar to our microphotograph (Plate LXI, fig. 3), cited by him in support of this description does not bear out his statement ; but this illustration (in the ' Explanation of Plates ') is correctly described by him as ' the pustular masses bursting through the tissues '. He describes the development of the pustules as superficial, whereas he illustrates the development as deep seated in the tissues of the host. Subba Rao has observed but failed to

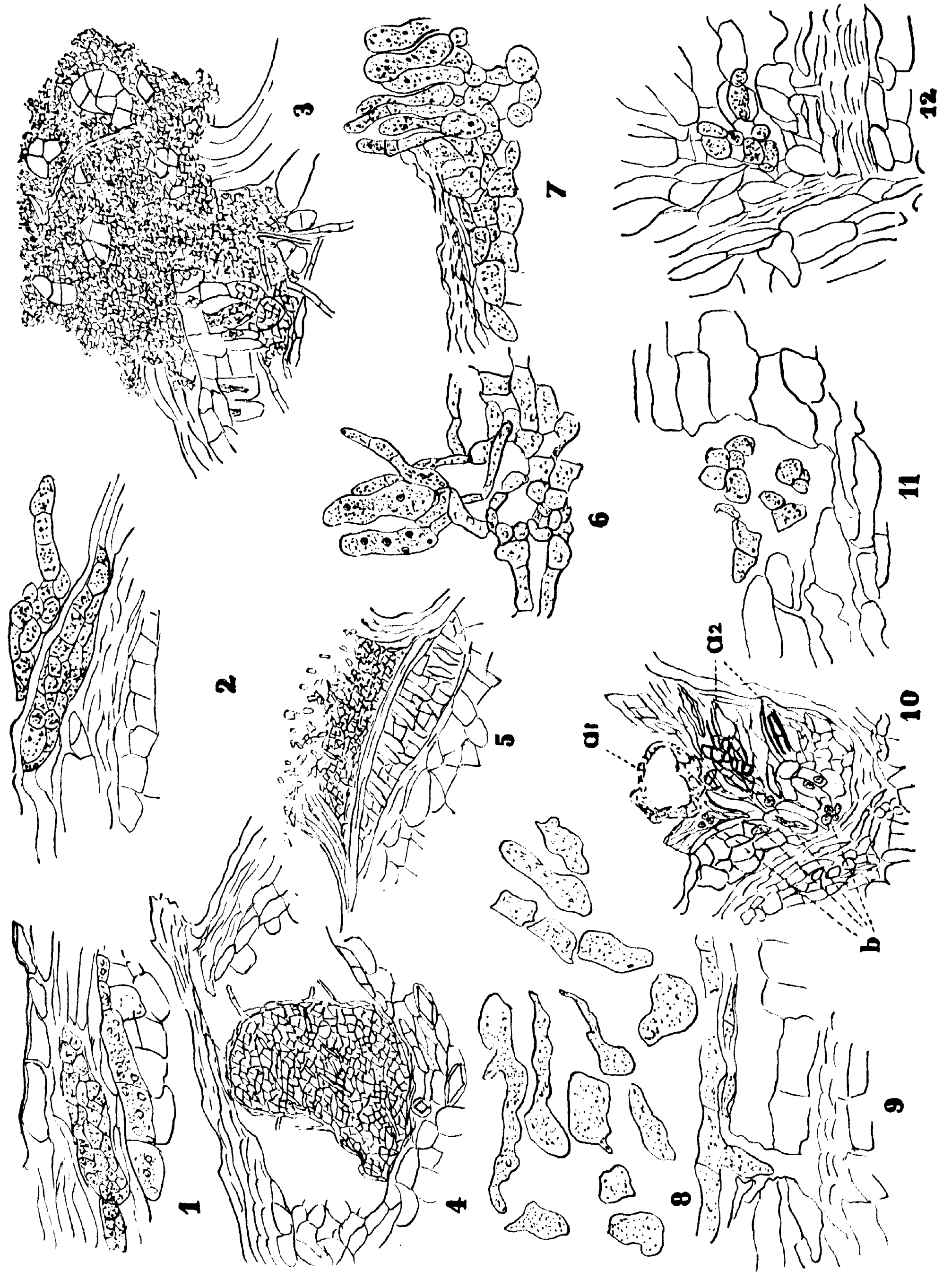
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PLATE LXIII.

1. A section of the bark showing an aggregate of cells formed in the sub-epidermal cells (× 600); 2. A section of the bark showing aggregates of cells inside and outside the bark (× 600); 3. A deep seated pustule bursting through the bark (× 130) (Note the presence of host cells in the erumpent part of the pustule and the columner sub-epidermal cells); 4. A dormant Necator pustule underneath the bark (× 600); 5. A Necator pustule over a lenticel (× 130); 6. Basidia (× 600); 7. Section of the bark with the basidial stage. Note the different layers of the basidia and the collapse of some of the hymenial cells forming a sort of a thick protective layer (× 600); 8. *Necator* spores. Some of the spores are germinating. 9. A hypha of the spinnengewebe mycelium entering the bark through a crack (× 600); 10. A section of the living bark showing the presence of *Diploidia* sp. and of *C. salmonicolor*: *a 1*, a pycnidium of *Diploidia* sp., *a 2*, *Diploidia* mycelium; *b*, scattered cells of *C. salmonicolor* (× 130); 11. A loose aggregate of cells formed by the hyphæ of spinnengewebe mycelium in a crevice in the bark (× 600); 12. A section through the living bark of a fork showing dormant cells of *C. salmonicolor* (× 600)

distinguish between the two types of pustules, that which originates on the bark from the spinnengewebe mycelium and that which develops from within the host tissues.

Microtomic and hand sections of the orange bark having these deep seated pustules clearly show that they consist of both fungus and host cells (Plate LXI, figs. 3 and 5 ; Plate LXIII, fig. 3). When the dormant mycelium in the cortex of the host tissue becomes active, there is an abnormal development of the host cells and a compact globular body with a fringe of hyphal strands, the immature pustule is developed beneath the brown epidermis or the phellem ; under pressure of the growth of the fungus this globular body bursts through the bark tissues forming an erumpent pustular outgrowth. In the part of the pustule which is outside the bark tissues the host cells are embedded in or surrounded by the pseudoparenchymatous fungus tissue, are thin-walled and wholly empty; their lumen is much bigger than that of the fungus cells ; remnants of collapsed host cells may also be readily seen ; but in the lower part of the pustule underneath the ruptured epidermis the host cells lose their uniform shape and become paliform ; they are wholly or partly filled with fungus cells which are usually pseudoparenchymatous, but occasionally are also fibrilar (Plate LXIII, fig. 3). When sections are stained with Cotton Blue and Saffranin the host cells in the pustules are stained red and the fungus cells blue. Subba Rao's illustration distinctly shows the pustules composed of host and fungus cells (Compare his illustration No. 4 with our Plate LXI, fig. 3 and Plate LXIII, fig. 3). At the base of the pustule in the cortex or phelloderm is an aggregate of closely septate fibrillate hyphae which has completely destroyed the host cells ; from this mycelial aggregate, which is not pseudoparenchymatous, hyphae spread out fan-like in the neighbouring cells except the stone cells.

There is a third type of the pustular stage, known as the *Necator* stage. When the spores are developed it can be readily distinguished from the other two types of pustules by its orange-red colour. This is the *Necator decretus* form of the fungus. The pustules are usually formed in vertical elongated streaks, as the pustules are developed on lenticels or in the tissues covered by the vertically elongated, slightly depressed green streaks which, as described by Webber and Fawcett [1935], are normally found in the grayish or brownish bark of an orange tree five to six years old.

The *Necator* pustule when developed over a lenticel is superficial ; it is generally seated on the narrow band of suberized cells (Plate LXIII, fig. 5). As observed by Rant [1911], it is also developed underneath the epidermis or in the periderm ; a number of these pustules may run together and are separated from each other by a partition wall formed by the host tissues. Even when spores have not been formed, sections of *Necator* pustules under the microscope can be readily distinguished from those of the sterile deep-seated pustules described above. The healthy tissues of the host are sharply delimited from the tissues destroyed by the *Necator* pustules ; from the base of these pustules there are no ramifications of the mycelial threads into the healthy tissues ; in the case of the other type of deep-seated pustules the hyphae are found to have penetrated the host tissues beyond the mycelial aggregates.

The *Necator* pustule has a superficial resemblence to a pycnidium, especially when it is full of the waxy orange-red mass of irregularly shaped spores ; but in its development it is different from a pycnidium. Brooks and Sharples correctly describe the development of the *Necator* pustule. Underneath the cuticle or in the periderm of the host branch there is an aggregate of fungus tissue forming a pseudoparenchymatous stroma (Plate LXIII, fig. 4) ; under favourable humid conditions this stromatic structure may burst through the bark and become erumpent ; the component cells of this stromatic tissue break up into individual cells, each cell being a spore (Plate LXII, fig. 1 ; Plate LXIII, fig. 5). As pointed out by Brooks and Sharples it is because of this mode of development of the spores that they are so irregular in shape and size (Plate LXIII, fig. 8). Under dry conditions the stromatic bodies originating underneath the bark tissues may remain dormant and embedded underneath the cuticle or the suberized or lignified tissues of the bark (Plate LXIII, fig. 4) ; or they may partly burst through the bark and remain partially covered by the ruptured cuticle of the layer of suberized cells ; they do not develop further and remain as pink coloured sterile pustules or cushions ; but under humid conditions they turn orange red in colour and this change of colour synchronizes with the breaking up of the pseudoparenchymatous tissue into numerous one-celled, irregularly-shaped bodies of spores.

The pustule formed over a lenticel is developed similarly. The hyphae form a pseudoparenchyma over the outer suberized layer of the lenticel ; the component hyphae do not extend beyond the pseudoparenchymatous tissue of the pustule. This pustule is in every way identical with that formed underneath the epidermis except that it is superficial and single.

Subba Rao [1936] has described the *Necator* pustules on tea branches to be ' composed of a plectenchyma which is tuberiform with a finer and resistant pseudoparenchymatous cortex and a looser, less homogeneous prosenchymatous core '. The *Necator* pustules on the orange branch have not been observed to have these two types of tissues which can be differentiated into a core and a cortex. The pustule is homogeneous in structure and the spores are developed by the component cells of the pseudoparenchymatous tissue of the pustules breaking up into individual unseptate cells as described above. They have never been found to ' originate by a process of abstriction from the paraplectenchymatous cells of the cortex ' as described by Subba Rao (Plate LXII, fig. 1 ; Plate LXIII, fig. 5).

The necator spores collectively are pink in colour but individually they are colourless. They are thin-walled ; they vary considerably in shape and size ; they may be angular or roundish, long or short ; they measure 8—20×5—10 μ. They germinate readily in water.

On rare occasions, there are on the *Citrus* bark, crust-like patches of fungus growth. This growth spreads over the surface of the bark, covering a very small and limited area, and is conspicuous when fresh by its bright pink or almost orange-red colour ; with age this growth becomes dull salmon coloured. It is different in appearance to the spinnengewebe or Höckerchen or other forms of this fungus. The margin of this growth is determinate but irregular in outline. The surface is not shiny as is that of spinnengewebe form and is not smooth. The surface is very much like that of a patch of coloured lime that has dried on the bark and has cracked. This crust-like growth is very much appressed to the bark ; when closely examined it is seen to have formed a sort of an irregular reticulum through the openings of which minute parts of the bark are distinctly visible as brown or black islands surrounded by strands of fungus mycelium. This is due to the incomplete development of the fungus over this area.

In sections the crust may be over 5-30 μ thick ; it is composed of a loose subiculum formed of long strands of hyphae ; these hyphae are broad and sparsely septate ; the walls of the hyphae may be encrusted. From this subiculum arises a broad layer of reticulated or pseudoparenchymatous cells (Plate LXII, fig. 3). In some cases the upper cells of this reticulated layer collapse, forming a thickish layer resembling the cuticular or suberized or thickened layer of an epidermis (Plate LXII, fig. 3 ; Plate LXIII, fig. 7); in other cases the upper cells of the reticulated layer develop the hymenial layer from which arise broad unseptate club-shaped bodies, the basidia, and septate, branched or unbranched broad hypha-like bodies with rounded apices, the paraphyses (Plate LXIII, fig. 6). The basidia measure 16·6—33·2×5—8 μ. From the hymenial layer the basidia may be developed in rows (Plate LXII, fig. 2 ; Plate LXIII, fig. 7) as suggested by Zimmermann's description [1904] and figures or the basidia may be scattered and irregularly arranged (Plate LXII, fig. 3) as observed by Brooks and Sharples.

Cystidia have not been observed. The basidia are plurinucleate, but sterile (Plate LXII, figs. 2 and 3 ; Pate LXIII, figs. 6 and 7) ; they bear neither sterigmata nor basidiospores. This hymenial layer with basidia and paraphyses is more deeply stained with Haematoxylon or Cotton Blue than the other layers of this form.

DISSEMINATION OF THE FUNGUS

Corticium salmonicolor on orange trees in this province is in an active state only during the wet season, when, as we have seen, it develops various forms, viz. the sterile pustular forms, the *Necator* form, the basidial form and the spinengewebe form. All these forms are capable of spreading the disease during the wet season to healthy plants or to healthy limbs of the same plant ; the infective material can be carried directly or on the scales of the exfoliating bark by rain-water, insects or wind. But all of these forms cannot play an important part in the annual incidence of the disease. The spinnengewebe form is short-lived and not capable of over-wintering or over-summering ; the mycelium is thin-walled and does not contain reserve food material ; even the white pustules which are developed superficially from this mycelium are equally seasonal in growth ; with the beginning of the dry season these white pustules and the spinnengewebe mycelium shrivel up. The basidial form, being rare and sterile, is equally unsuitable for the perpetuation of the parasite from one wet season to another. The *Necator* form that has developed spores would also be capable of disseminating the fungus only during the wet season as the spores are thin-walled, unless their waxy covering protects them through the long dry period ; but the *Necator* pustules with their stromatic tissues not broken up into spores would be eminently suitable to withstand dry weather and would be resistant to adverse conditions, especially those that are underneath the bark or the thickened epidermis. The sterile pustules and aggregates of fungus cells which are developed in the tissues of the bark would also serve as potential sources of infection when the dry period is succeeded by the wet season, especially those which are dormant in the living tissues of the bark.

The possibility of the strands of mycelium found in the callus tissues round cankers or in the tissues of lenticles remaining dormant cannot be overlooked. It is not improbable that these isolated strands of hyphae over-winter and over-summer in the plant tissue and resume their growth in the rainy season. Field observations do not overrule this source of infection. In some cases, in the rainy season, in absence of any of the other forms of the *Corticium* fungus, a few isolated and scattered white sterile pustules bursting through lenticles or the bark round cankers or in the fork have been observed ; it is not improbable that they may have originated from the dormant mycelium inside the bark.

Brooks and Sharples [1914] have recorded that a species of *Nectria* is often found along with *Corticium salmonicolor* ; on orange branches also these two fungi are associated together, especially when the limb affected by the pink disease is thick. The perithecia of *Nectria* sp. have been found to be superficial and seem to grow on the dead outer tissues of the bark. There is another fungus which is more intimately associated with *C. salmonicolor*, and that is *Diplodia* sp. (Plate LXIII, fig. 10). The growth of this *Diplodia* is both external and internal ; the mycelium travels inside the cortex ; stromatic masses are formed in the bark tissues, and pycnidia burst through the epidermis or phellogen, as do the pustules of *C. salmonicolor*. The hyphae and stromatic masses of *Diplodia* sp. can be readily distinguished from those of *C. salmonicolor*. The fungus tissue of *Diplodia* is brown or honey coloured, thick walled ; the cell contents are not readily visible because of the dark-coloured walls. The fungus tissue of *C. salmonicolor* is hyaline and thin-walled, and the cell contents are granular. The aggregates of fungus cells of *C. salmonicolor* are often embedded in or surrounded by the stromatic tissues of *Diplodia* in the host tissues. It is not improbable that the thick-walled stromatic masses of *Diplodia* sp. in the outer or inner tissues of the bark serve as a protective covering to the scattered thin-walled aggregates of the pink disease fungus and enable them to tide over the dry season. It has been mentioned above that the hyphae from the spinnengewebe mycelium enter the bark tissues through lenticels or through cracks in the bark ; it is not improbable that the primary infection of the host tissues may also be through the outer cells of the bark killed or weakened by *Diplodia* sp.

CONTRIBUTING CONDITIONS

In Balaghat district, citrus orchards are only a few in number and yet the incidence of pink disease is annual and usually in an epidemic form ; whereas in other parts of the Central Provinces, e.g. Nagpur district, there are extensive areas under citrus but the disease is generally absent, or where found, it is sporadic and confined only to a few isolated trees. In Balaghat the average rainfall from 1 June to 31 October is 60·83 in., and the average number of rainy days for the same period is 63·1 ; whereas in Nagpur, Jubbulpore and Betul for the same period the average rainfall is 44·79, 51·28 and 40·06 in. respectively, and the average number of rainy days is 54·0, 55·5 and 51·3 respectively. The high average rainfall and the larger average number of rainy days in Balaghat may account for the presence of the disease in an epidemic form. Our inoculation experiments at Nagpur have shown that the inoculated plants are not a source of infection to healthy citrus plants in the same plant house ; and that the infection from the successfully inoculated twig does not spread to the healthy limbs of the same plant the following wet season. This shows that climatic conditions at Nagpur at least are not suitable for the spread of this disease.

INOCULATION EXPERIMENTS

Inoculations of potted orange (*Citrus aurantium*) and sour lime (*C. acid* plants, two to three years old, with pure cultures of *Corticium salmonicolor* isolated from orange and mango plants attacked by this fungus were carried out at Nagpur. The inoculum was cultivated aseptically on sterilized small pieces of orange twigs ; they were tied to the stems of the plants to be inoculated ; in some cases water-soaked cotton wool was wrapped round the stem and the inoculum. The inoculated part of the stem was enclosed in a glass or celluloid chimney the open ends of which were closed with wet cotton wool. The inoculations were successful. At first the spinnengewebe form of the fungus developed on the inoculated limb ; later, white pustules were formed along with the spinnengewebe mycelium ; small drops of gum were seen exuding from very thin small cracks in the bark covered by this mycelium ; the leaves of the inoculated twig turned yellow and wilted ; with the further progress of the inoculation the part of the twig above the inoculated area died back. As long as the inoculated limb was kept under moist conditions, by enclosing it in a chimney the ends of which were plugged with wet cotton wool, the spinnengewebe mycelium spread rapidly and developed the characteristic pink colour ; but soon after the covering was removed and the infected limb was exposed to dry conditions the growth of the spinnengewebe mycelium was checked, the white or pink colour gradually faded ; small cankers developed where formerly gum had exuded. Some months after these cankers were formed, sections were taken through the callus ring round them and through the bark of the fork where the spinnengewebe mycelium had spread from the inoculum ; the sections showed the presence of inter-cellular hyphae as found in the naturally infected plant.

The inoculated plants were kept under observation for two seasons ; there was no further visible progress of the pink disease except that the inoculated limb ultimately dried up ; not only was there no sign of the disease extending from the infected limbs to the healthy limbs of the inoculated plants but there was also no spread of the disease to the other uninoculated orange and lemon potted plants kept close together in the same plant house.

CONTROL MEASURES

The question of the control of pink disease of orange in Balaghat district is of importance if orange cultivation is to be encouraged.

In Balaghat, citrus orchards are very near forests and therefore there seemed to be the probability of the infection spreading to the citrus trees in the wet season from diseased forest trees outside the orchards. Therefore search was made for two seasons for pink disease infected trees in the forest near the orchards. Only two trees were found to be diseased and these too not very badly ; one was a mango (*Mangifera indica*) tree, and the other was a jack fruit (*Artocarpus integrifolia*) tree. It therefore seems that the forest trees are not a serious source of infection to the neighbouring citrus orchards, and that the infective material is present in the citrus orchard itself.

Preventive spraying and pruning of diseased parts have been found to be effective for the control of this disease not only on shrubs, like tea and coffee, but also on *Hevea* (rubber) and citrus trees. In Balaghat, pruning of dead limbs and spraying before the break of the rains have not always given satisfactory results. At first, when the trees were young, these operations could be satisfactorily carried and so the results were encouraging, but with the annual increase in the number and size of the branches there were increasing difficulties in carrying out these two operations satisfactorily. We have seen that the pink disease fungus on orange trees develops pustules and cellular aggregates inside the plant tissues, and that they remain well protected by cuticulerized and suberized cells of the bark ; this protective covering may very probably help these bodies to lie dormant during the dry season ; and the spray liquid would not reach these dormant bodies. During the wet season they are capable of becoming active and are then potential sources of infection. The infective material may be either *Necator* spores developed from the dormant pustules, parts of pustules or of cellular aggregates attached to the exfoliating bark which can be carried from tree to tree and from branch to branch by rain water, wind or insects. Spraying might protect the tree from catching the infection from these sources, but to be effective the spraying would have to be repeated very often and the forks especially would have to be kept well covered with a fungicide. It is improbable that spraying, as a prophylactic measure, would in itself be very effective in the control of this disease. As long as there are in the orchard plants with dormant infection spraying would only partially control the spread of the disease from the infected trees of the previous season. Therefore, during the dry season it would be advantageous to go over the infected trees individually and examine them for the presence of cankers. These cankers should be carefully scraped and the wounds dressed with a suitable fungicide like Bordeaux paste or preferably creosote oil. Since the fungus has been found in the tissues of the bark of a fork, the forks of infected trees, especially those formed by the main branches, should also be scraped and dressed with a fungicide.

In the wet season, limbs of the tree as soon as they are found to be diseased should be cut back much beyond the extent of the infection to ensure the complete destruction of the parasite ; the trees should be examined at short intervals for new cankers and fresh pustular growths, which should be scrapped to prevent the fungus from establishing itself on them. The wounds should be dressed with Bordeaux paste or creosote oil.

SUMMARY

Pink disease of orange trees in the Central Provinces, caused by *Corticium salmonicolor* B. & Br., is described. It is usually in an epidemic form in Balaghat district ; it is not widely distributed throughout the province.

On orange trees the following forms of the fungus have been observed ; the spinnengewebe form, sterile pustular forms, the *Necator* form and the basidial form.

The spinnengewebe mycelium is mostly superficial ; it penetrates the bark only through wounds. Over thin-walled lenticels and over broken tissues of the bark the hyphae form loose aggregates of cells.

The sterile pustules are either white or pink or orange-red coloured. The white pustules develop either superficially on the outside of the bark or from within the bark tissues. The pink or orange-red pustules originate in the subepidermal tissues of the bark.

The *Necator* pustule resembles the sterile pustules till it develops spores. Spores are formed by the cells of the pseudoparenchymatous tissue of the pustule separating from one another ; the spores are one-celled, hyaline, and very variable in size and shape.

The basidial form is rare. Basidia are either formed in a row from the hymenium or are scattered ; they are sterile and plurinucleate ; sterigmata are absent.

Dormant mycelium has been observed in the callus formed round cankers and in the bark tissues of a fork.

Inoculations of orange and lemon trees have been successful in Nagpur. The infection from the successfully inoculated plants did not spread the following wet season to the healthy plants in the same plant house ; the infection did not even spread from the diseased limb to the healthy limbs of the same plant.

Climatic conditions may be the cause of the disease being in an epidemic form in Balaghat district, where there are only a few orange gardens, and the disease being sporadic and confined to only a few isolated plants in other places where orange gardens are numerous.

Control measures are suggested.

REFERENCES

Brooks, F. T. and Sharples, A. (1914). *Dept. Agric. F. M. S. Bull.* **21**
Butler, E. J. (1918). *Fungi and diseases in plant*
Lee, H. A. and Yates, H. S. (1919). *Philip. J. Sci.* **14**, 6
Rant, A. R. (1910). *De djamoer oepas-zeikte, Teysmannia* **20**
————————(1911). *Bull. Jard. Bot. Buitenzorg* Ser. **2**, No. 4
Subba Rao M. K. (1936). *United Planters' Assoc. S. I. Tea Sci. Dept. Bull.* **10**
Webber, I. E. and Fawcett, H. S. (1915). *Hilgardia* **9**, 2
Zimmermann, A. (1910). *Centralbl. f. Bakt. U. S. W. IIte. Abt. Bd.* **7**
———————— (1904). *Mededeelingen uit ' S Lands Plantentuin* **67**

THE SOFT-ROT OF APPLE FRUIT IN KUMAUN

BY

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(With Plates LXIV and LXV)

A STORAGE disease of apple fruit caused by *Penicillium expansum** Lk. was first recorded in Chaubattia (United Provinces) in 1934. Kheswalla [1936] recorded it from Baluchistan. It is known in all apple-growing countries and can cause 75 per cent loss of apple fruits in storage. The earlier workers referred any blue mold attacking apples to *Penicillium glaucum* Lk. and this name is still retained by some writers even at the present time. But now it has been recognized that *P. expansum* Lk. is the most common and destructive of the various species of *Penicillium* known to attack apple fruits in storage. It is variously called soft-rot, blue-mold, bin-rot and *Penicillium* rot. There is a peculiar and characteristic musty odour, which is invariably present in diseased fruits. This odour is the first noticeable feature of this fruit decay, but the softness of the affected tissues is significant character of the disease and hence its common name is soft-rot.

Symptoms of the disease

The characteristic musty odour given off from apples affected with soft-rot is a very accurate diagnostic symptom so far as determining the presence of the disease in a lot of fruit is concerned. The rotted area turns soft and watery, light or yellowish brown in colour. In lesions where a considerable portion of the apple is involved the skin becomes wrinkled, sometimes in a concentric manner. Young spots may begin anywhere on the surface of the fruit wherever there is the slightest injury in the skin (Plate LXIV, fig. 1*a*). Diseased spots sometimes start from stem-end of apple (Plate LXIV, fig. 1*b*). On cutting through the rotted area of the apple it is found to be light brown in colour and watery (Plate LXIV, figs. 2*a* & *b*). The rot is primarily one of the ripe fruits and increases with the ripeness of the fruits ; green fruits as a rule are not affected. The fungus gains entrance often through the stem-end and less frequently through the calyx-end. Under conditions of very high relative humidity a bluish green sporulating growth, which is nearly snow-white in its initial stages appears (Plate LXIV, figs. 3*a* & *b*). Hence the two characteristic diagnostic characters of *P. expansum* Lk. are (1) musty odour and (2) the formation of conidial tufts or coremia on the surface of well-developed lesions. This fungus was observed on almost all the varieties of apple grown in Kumaun.

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* The culture of the fungus was sent to Mr S. F. Ashby, the former Director of the Imperial Mycological Institute, Kew, England, who identified it as *Penicillium expansum* Lk.

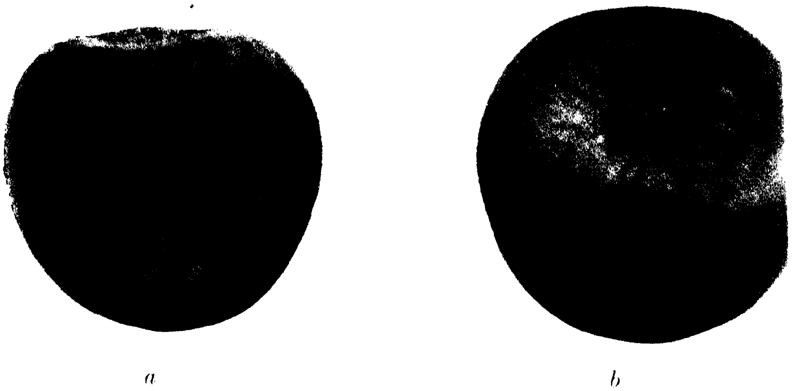


FIG. 1. Soft rot (*a*) on Delicious apple, (*b*) at the stem end of Delicious apple

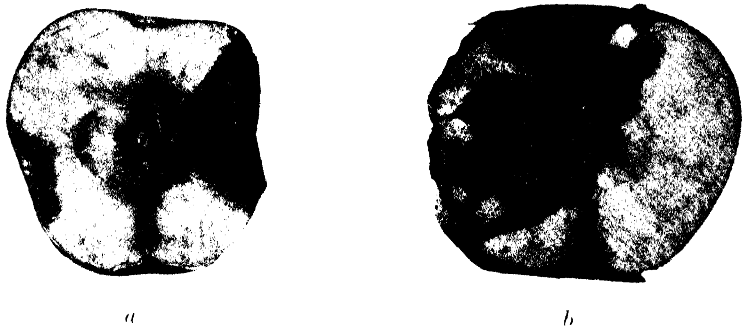


FIG. 2. An apple (Delicious) cut open showing internal rotted area

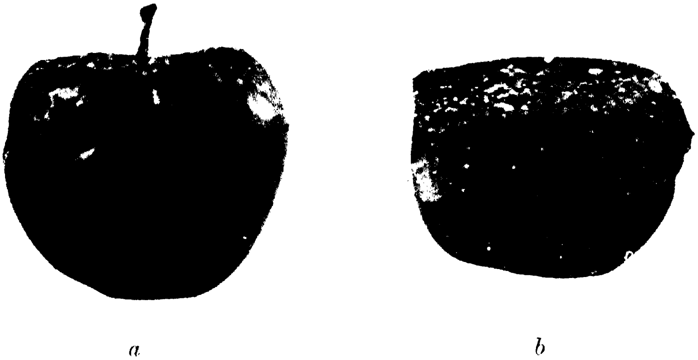
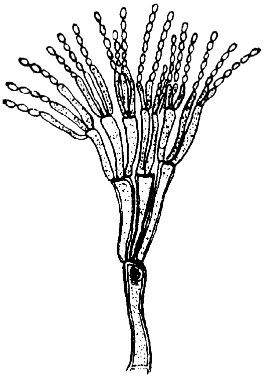


FIG. 3. Fructification of the fungus on the surface of the fruit



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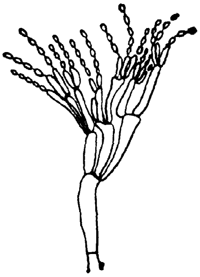

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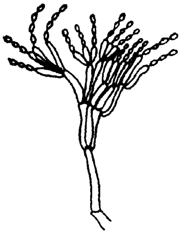

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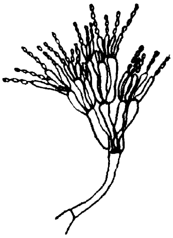

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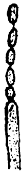

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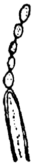

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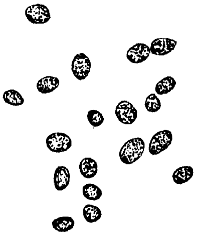

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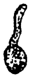

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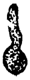

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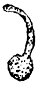

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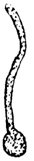

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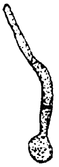

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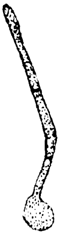

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FIG. 1. Conidiophores with conidia in chains (×1,066)
FIG. 2, 3 & 4. Conidiophore with conidia in chains (×480)
FIG. 5 & 6. A single conidiophore with conidia (×1,066)
FIG. 7. Conidia (×1,066)
FIG. 8-13. Conidia germinating (after 48 hours at 20°C.) (×1,066)

MORPHOLOGY

The greenish cushions or pustules which appear on the surface of the fruit are tufts of fruiting stalks of the fungus which arise from the mycelium within. A number of hyphae grow in erect fashion at the same point ; their general arrangement is like that of an inverted broom without the handle. The tips of these hyphae, or conidiophores, become branched in a digitate fashion, and at the end of each stalk is developed a chain of spores or conidia (Plate LXV, figs. 5-6). The conidiophores of the fungus are irregularly penicilliately branched (Plate LXV, figs. 1-4). Conidia are catenulate, hyaline or coloured. They measure $2 \cdot 1 - 4 \cdot 9 \times 2 \cdot 1 - 4 \cdot 4\mu$, the average being $3 \cdot 7 \pm 0 \cdot 03 \times 3 \cdot 69 \pm 0 \cdot 01 \mu$ in diameter (Plate LXV, fig. 7). These conidia readily germinate in tap water at room temperature (Plate LXV, figs. 8-13).

PATHOGENECITY

The pathogenecity of the fungus was proved by means of a series of inoculation experiments by the (*a*) Granger and Horne [1924] cork-borer method and (*b*) by causing injury to the skin of apple fruit aseptically by means of a flamed scalpel and then inoculating. The fruits selected for inoculation were perfectly sound and were all of one variety (Bramley's seedling), size and maturity. These fruits were surface sterilized by dipping them in potassium permanganate solution (2/1,000) for 20 minutes then washed thrice with sterilized water and the surface wiped with absolute alcohol. For the cork-borer method ten fruits were selected, eight were inoculated with the fungus and two served as control ; the latter ones were inoculated with sterilized distilled water. Each fruit after inoculation was wiped with absolute alcohol and then wrapped with sterilized wax paper and sealed with bees wax. All these fruits were kept inside a small glass cage kept in the laboratory. In 24 days all the inoculated fruits completely rotted away with the formation of fructification on the surface in some fruits while the control ones remained unaffected. The fungus was re-isolated from inside the rotted fruits and resembled the parent culture in all respects. For the other method eighteen fruits of Bramley's seedling were at first surface-sterilized in the same way as described above. Out of these, six fruits were kept in a sterilized dish and injured at a number of places, while six fruits were kept in another sterilized glass dish but were not injured. Similarly, six fruits were injured and six were left uninjured into two separate glass dishes and these served as control. A heavy spore suspension was sprinkled by means of an atomizer in the first two sets (injured and uninjured) while sterilized distilled water was sprinkled over the control ones (injured and uninjured). On the fourth day light yellowish brown spots began to appear round about injured surfaces of apple, but there was no sign of infection in the uninjured fruits. By the eighth day all the injured fruits were completely rotted due to infection from spores. There was no infection in the control fruits. Thus it is clear that the fungus *Penicillium expansum* Lk. is a weak parasite and cannot enter through uninjured surfaces of apple fruits.

METHODS OF CONTROL

The onslought of this obnoxious storage disease can very well be minimized by the grower and the dealer if the following methods of control are adhered to.

Since the fungus is a wound parasite, all attempts should be made to avoid injuries.

(1) In order to avoid injuries during picking apples, the finger nails of the picker should be short or they should put on smooth gloves.

(2) Prevention of the skin injury during grading. The grader should be so adjusted that no fruit falls upon another, or rolls so as to come into violent contact with another, or with its stem.

(3) During packing the fruits should not be forced upon one another, because in doing so often the stem of one fruit injures the epidermis of another. The fruits should be wrapped with oil paper (double boiled linseed oil) and in packing the pad of the wrapping paper should be so placed as to act as a cushion and thus minimize the danger of bruising.

(4) Removal of all fruits showing the least signs of skin injury or blemish or rotting. These fruits are likely to form spores on the surface of the fruits which will act as a source of infection to other fruits.

(5) Spray treatments are useless, for no spray treatment on the trees will counteract injuries caused through subsequent careless handling.

DISCUSSION

The soft-rot of apple fruits is the worst storage disease and can cause 75 per cent rot of apples. The fungus is omnipresent, but the fact that it cannot enter through the healthy skins of the apple suggests that the method of controlling this disease lies in the careful handling of the fruits.

The possibilities of the bruise caused at the picking by pickers with large nails are obvious and can be avoided by instructing the pickers to cut their nails or make them put on soft gloves. In packing, the fruits should be wrapped in oiled wrappers and the packing must not be too tight to cause bruises. In grading, the grader should be so adjusted that one fruit must not fall violently over the other or its stem. The removal of every fruit showing the rotting is a very effective method of controlling the disease, for, if the affected fruit is left there, it will surely, in course of time, form fructifications on the surface of the fruit and thereby cause infection to neighbouring fruits Spraying the fruit is useless.

SUMMARY

(1) The fungus causing soft-rot disease of apples in storage in Kumaun is identified as *Penicillium expansum* Lk.

(2) The symptoms of the disease are its characteristic musty odour with rotted watery light or yellowish brown areas. Under conditions of high humidity bluish green sporulating growth appears on the surface of the rotted fruit. The fungus also starts from the stem-and calyx-ends.

(3) The morphology of the fungus is described in detail in the text. The conidiophores are irregularly penicilliately branched. Conidia are catenulate, hyaline or clear coloured.

(4) A single spore culture of the fungus was obtained. The fungus was inoculated into the healthy apple and again re-isolated and resembled the parent culture in all respects.

(5) The infection experiments showed that the fungus cannot enter through uninjured healthy skin of the apple.

(6) The fungus is a saprophytic one and is found growing on a large number of dead organic materials and produced vast number of spores. These spores float in the air and if they happen to settle down on injured surfaces of apple, they cause rotting.

(7) The effective methods of control consist in carefully handling the fruits so as to avoid injuries during picking, grading and packing the fruits.

ACKNOWLEDGEMENTS

My sincere thanks are due to Mr P. K. Dey, Plant Pathologist to Government, United Provinces, for guiding the work and the Imperial Council of Agricultural Research for financing the scheme of Hill Fruit Research Station, Chaubattia. Gratitude is expressed to Mr S. F. Ashby, the former Director of the Imperial Mycological Institute, Kew, Surrey, England, for kindly indentifying the culture.

REFERENCES

Granger, K. and Horne, A. S. (1924). *Ann. Bot.* **38**, 401
Kheswalla, K. F. (1936). *Agric. and Livestock in India* **6**, 204-15

FATAL TEMPERATURES FOR THE PINK-BOLLWORM [*PLATYEDRA GOSSYPIELLA* (SAUND)] OF COTTON

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THE pink-bollworm, *Platyedra gossypiella* (Saunders), of cotton has come into great prominence during the last two decades in almost all the cotton-growing tracts of India, excepting the extremely hot and dry areas of the south-western Punjab.

Preliminary surveys carried out in the United Provinces in 1921 established beyond doubt that the pink-bollworm had become a major pest of cotton in that province. With financial aid from the Indian Central Cotton Committee, the Entomologist to the Government, United Provinces, investigated various methods of controlling the pest for several years (1925—32) and came to the conclusion that the most effective method of control was to prevent the carry-over of the hibernating larvae inside the harvested seeds by effective heat treatment [Richards, 1938]. He also reported that exposure of the infested seed to sun for a couple of hours in the afternoon (1—3 P.M.) during April and May in the United Provinces was sufficient to kill all the larvae resting within the seeds.

On the basis of this work, sun-heat treatment of cotton seed was carried out on a large scale in certain districts of the United Provinces. Although sun-treatment is a measure involving little expense beyond manual labour, its value is very limited. Its effect may be lowered by several factors such as wind, clouds, etc. which are beyond human control. Again, while the method is easily applicable to small quantities of cotton seed, it is hardly practicable in the case of large stocks usually handled under factory conditions. Moreover, during the greater part of the ginning season, the sun temperature is insufficient to kill the caterpillars, as it synchronizes with milder weather conditions. On account of these difficulties, the use of the Simon heating machines was advocated for large-scale operations in factories. The capital cost of a suitable heater and its accessories was, under pre-war conditions, about Rs. 10,000, which small factories cannot afford. Before advocating legislation that all factories in the province should provide themselves with Simon heating machines, the Director of Agriculture, United Provinces, sought the advice of the Imperial Entomologist, Imperial Agricultural Research Institute, New Delhi.

Although a fair amount of data on the lethal temperatures for this pest was available from the work done in other countries, it was thought that these results may not be exactly applicable to the larvae adapted to our climatic conditions. It was, therefore, considered desirable to investigate the behaviour of the pest to different heat treatments under Indian conditions.

The objects of this enquiry were briefly to determine :—

(*i*) The effect of exposing naked larvae to various constant high temperatures on their viability.
(*ii*) Similarly, the effect of exposing infested seeds of cotton to various temperatures on the mortality of larvae hibernating within.
(*iii*) Part played by relative humidity of air in determining the fatal effect of temperature on larvae.
(*iv*) Influence of sun's heat on the viability of larvae inside seeds.
(*v*) Effect of the above treatments on the viability of cotton seed.
(*vi*) Maximum exposures to various high temperatures tolerated by the seed.
(*vii*) Effect of variety of cotton seed on the larval mortality under various conditions of heat treatment.

We wish to express our appreciation of the help received from Mr Ghulam Ullah, Assistant to the Imperial Entomologist, in carrying out experimental work with keen interest and great care.

REVIEW OF PREVIOUS WORK

In view of the possibilities of heat treatment being a useful control measure against pink-bollworm, considerable work has been done on the fatal temperatures for this insect in several cotton-growing countries of the world. Gough and Storey [1913], working in Egypt, dipped infested cotton seeds in water maintained at different temperatures. They found that dipping the seeds for five minutes in water at 50°C. killed 97 per cent of the larvae, while dipping for two minutes at 55°C. gave complete larval mortality. The germination of seeds was not affected. The viability of seeds was only affected (about 20 per cent) when they were dipped for five minutes in water at 75°C. Similarly, seeds exposed to hot air in a chamber, the tempeature of which was roughly controlled, gave the following results :—

Air temperature in the chamber (°C.)	Exposure (minutes)	Larval mortality (per cent)
69—80	5	Partial
About 80	4	100
63—72	10	75
75—94	10	100

Later on, Storey [1915], as a result of his large-scale experiments performed in better insulated machines in which the seed could be exposed in thin layers over several circulating canvas belts, got the following figures :—

Air temperature (°C.)	Exposure (minutes)	Larval mortality (per cent)	Remarks
About 60	10·5	100	Germination not affected
60—70	6·5	100	Do.
70—80	3·5	100	Do.
85—90	3·5	..	Evidence of germination being affected

He further noticed that temperature remaining the same, if the intake of seeds was increased so that seeds were exposed in thicker layers, the rate of mortality was lowered.

Similar experiments were carried out by Gough [1916] in a hot machine, the temperature inside which was controlled by the opening or closing of a damper placed between the hot air generator and the chamber. His results are summarized below :—

Chamber temperature (°C.)	Temperature (°C.) of seed at the exit	Exposure (minutes)	Larval mortality (per cent)
75	47	9	96
80	50	9	100
80	48	7	97
85	50·5	7	100
80	..	5	38
90	47·75	5	100

It will be observed that there was great difference between the temperature inside the machine and that at its exit. As a result of these experiments, Gough's chief conclusion was that to ensure complete larval mortality, the temperature of the chamber and exposure of seeds should be so regulated that the temperature of the seed at the exit is about 50°C. He admitted that at some points in the chamber close to the hot pipes the temperature went as high as 170°C. (which is extremely lethal) but he argued that as the seeds came into contact with such places only for a moment or so, no harm was done to their viebility.

The experience of Storey [1916] on the treatment of cotton seed in the Simon's hot-air machine made it clear to him that obtaining a certain requisite seed temperature at the exit was not enough. He found that all minute details in exposing, handling and final disposal of the seeds had to be taken into account to determine the final effect of the treatment. For instance, in practice, the temperature of the machine was maintained at 55°—56°C. and the seeds passed through it in about five to seven minutes. After coming out, if the hot seeds were put into sacks and kept aside for some time, complete mortality among the larvae was observed. On the other hand, if after the hot treatment, the seeds were not put into sacks but were allowed to cool in the open, several larvae survived. This showed that sacking or otherwise handling the seed subsequent to heating inside the machine had important influence on the result of heat treatment. Obviously, sacking resulted in the maintenance of, if not further rise in, temperature which ensured complete mortality of the larvae.

The methods of heating cotton seed evolved in Egypt were however not found to be equally successful in Texas (U. S. A.), owing probably to the different nature of the seed, the behaviour of the insect, etc. [McDonald and Scholl, 1922]. As a result of several experiments, these authors concluded that the seed must be exposed to a higher temperature inside the machine than that which was to be obtained at the exit. Under strictly controlled conditions although an exposure of three minutes to 58°C. gave complete mortality, in practice seeds had to be uniformly heated at 63°C. for 3½ minutes to free them of all living bollworms. Further, they found that it was possible to heat the seeds up to 74°C. for a short while without injuring their germination. However, seeds could survive much higher temperatures provided the exposure was less. For instance, a germination of 93 per cent was observed after an exposure of one minute to 160°C.

Bredo [1934], reviewing the work carried out in Egypt, Belgian Congo, etc., concluded that a machine without an automatic feeder was inefficient, as heat penetrated imperfectly if the seeds were admitted in a thick layer. He further confirmed Gough's observations that when the temperature at the exit of the machine was 50°C., that of the interior might be above 100°C. Again, the exit thermometer might register 65°C. if the seed was dry and 60°C. if it was moist. Commenting upon the Egyptian experiments, he stated that exposure of five minutes and exit temperature of 55°C. proved effective only if the seed was subsequently kept in sacks for a period of two hours. If the seed was not put into sacks immediately, its temperature at the exit must be at least 65°C. for the same length of exposure.

With regard to the use of Simon heater in the United Provinces, Richards [1938] concluded that it was essential to so regulate the steam input that the seed at the exit reached a maximum temperature of 60°C. It was further found that dry seed in a dry atmosphere retained its normal viability up to 82°C. In the presence of moisture, however, some loss of seed viability was observed even at 63°C. A temperature of 62°C. was, therefore, considered as the maximum to which seed should be actually heated.

From this brief review of previous work it will be obvious that exact temperature requirements to get complete larval mortality depend on a large number of factors. For instance, the thickness of layer in which seeds are passed through the heating machine, the extent of stirring, the insulation of the machine, the duration of exposure, the temperature of the atmosphere from which the seeds are brought and to which they are taken after treatment all affect the temperature to which seeds get actually heated. Moisture plays an important part. Apart from its effect on larvae, which was hitherto not clear, Bredo [1934] showed that machine temperature, and the process and duration of exposure remaining the same, dry seed registered 5°C. higher temperature at the exit than the moist seed, showing thereby that dry seed got heated quicker than the moist seed. In the same way the combined effect of temperature and humidity on the viability of seed has to be carefully kept in view. According to Richards [1938] moist seed is more susceptible to high temperature than dry seed. It was probably for such reasons that the methods evolved in Egypt, when tried in Texas were not found to be equally successful. It is, therefore, clear that the results obtained on fatal temperatures for the pink-bollworm vary widely under different environmental conditions of the country and the machine in which treatment is carried out, and results obtained in one country must be tested in the other country before they are adopted for general use. In fact the detailed procedure of large-scale treatment must be standardized for each country.

MATERIAL AND METHOD

The cotton crop of 1939-40 on the estate of the Imperial Agricultural Research Institute was badly infested with pink-bollworm and afforded abundant material for our investigation. About two maunds of cotton seed of indigenous Mollisoni variety and three maunds of American variety (289 F) were examined soon after the harvest and double seeds (containing the larvae) separated. Almost all the larvae were full grown and appeared to be in a state of hibernation.

At first, preliminary experiments were carried out by placing the double seeds in a copper or glass tube about one inch in diameter, dipped in hot water maintained at a constant temperature, with a fluctuation of not more than ±0·25°C. It was noticed that the air space between the seeds acted as a fairly good insulator in the transmission of heat from the wall of the tube to the centre of the seed mass. A thermometer fitted in a cork was placed in the centre of the seed mass in the tube. The rate of rise in temperature was noted every minute and the records are given below :—

TABLE I

Rate of rise in temperature of cotton seed placed in a tube immersed in hot water

Temperature of water (°C.)	Container	Temperature (°C.) of seed recorded every minute								
		1	2	3	4	5	6	7	8	9
68	Copper tube	42	52	59	62	64	65·5	66·5	67·5	67·5
	Thin glass tube.	42	51	57	59	64	65	67	68	68

It will be noticed that surface temperature of seeds in the centre of the tube reached within a degree of the water temperature in seven to eight minutes. Thus the temperature of the larvae within the seeds would take a still longer time to reach that of the water bath. There was, however, little difference between a copper and a glass tube at the end of this period, although in the beginning the copper tube got hotter much more quickly than the glass tube.

In order to reduce this error to the minimum it was decided to expose the seeds to high temperature by spreading them in a single layer. This was done inside a thermostatically controlled hot oven. Thus the seeds, immediately after the exposure, came in touch with an atmosphere already at the desired temperature. This reduced the interval which heat took to penetrate from the water bath to the centre of the tube in the previous experiments. A sensitive thermometer placed with its bulb in contact with the seed layer showed that the seed acquired the temperature of the oven, which was 70°C. in a particular experiment, in three minutes. When the seed was introduced into the oven, the temperature of the latter fell down by one degree. As the extent of fall and the time for which it lasted are extremely small, it may be claimed that results obtained with these experiments are fairly reliable. The effect of this fall will be still more insignificant in experiments involving exposures longer than five minutes, because the temperature adjusted itself within the first three minutes.

These experiments also suggest that in practice not only must the seed be exposed to hot air in a very thin layer but the air must be kept in motion. In a calm atmosphere the seed absorbs heat from the surrounding layer, the temperature of which consequently drops. Now as the air is a bad conductor of heat the drop in temperature of the layers of air immediately surrounding the seed is not made up at once and in practice the seed remains exposed for some time to a temperature lower than that of the main atmosphere inside the chamber. But if the air is in motion every moment fresh air at the required temperature strikes the seed surface the old cooler air being constantly taken away and warmed up.

FATAL TEMPERATURES FOR NAKED LARVAE

The actual temperature to which the larvae themselves are exposed and as a consequence of which they die as distinct from the temperature to which the seed is exposed is of fundamental importance and forms the basis of heat treatment ; yet little work has been done to test the naked larvae (taken out of the seed) with regard to their heat resistance. In almost all previous investigations workers have exposed larvae enclosed in seeds to different temperatures. Although this is the manner in which larvae are to be subjected to heat treatment in practice, it must be realized that temperature of the hot air to which seeds are exposed remaining the same, the temperature attained by the larvae within the seeds, which is of real importance, depends on several other factors, such as the temperature of the seeds before exposing to heat, the thickness and hairyness of the seed, its moisture content, the temperature to which seed is brought back after treatment, etc. For instance, seed at an original temperature of 10°C. may require double the exposure to a given high temperature to effectively kill all the larvae inside them as compared with another lot at an initial temperature of say 40°C. It is, therefore, essential to know in the first instance the temperatures and their durations which are fatal to naked larvae themselves.

In the case of moderately high temperatures of 45°C. and 50°C., larvae were exposed under controlled humidities on a glass plate inside desiccators as explained in the next section and the results are set forth in part A of Table II. At 50°C., and higher temperatures, where the exposures were short, the humidity was not controlled and larvae were exposed on a copper plate in the following manner :—

A known number of naked larvae were placed in a double-walled copper container. The space between the two walls was filled with water at the temperature to be tested and the container placed in hot oven at the same temperature. The larvae were thus in contact with hot copper wall which readily transmitted its heat to them and at the same time recouped its loss by taking heat from water inside the container. The air surrounding the larvae was also at the required high temperature of the oven. The results thus obtained are summarized in part B of Table II.

It will be observed that an exposure of naked larvae for about 24 hours to 45°C., 1—2½ hours to 50°C., 7—10 minutes to 55°C., five minutes to 60°C., two to three minutes to 65°C. or one minute to 70°C. proved completely fatal. Thus, in practice, the seed should be so treated as to ensure that the larvae within the seed get the necessary exposure to any particular temperature mentioned above. The longer exposures are, however, impracticable from commercial point of view as time factor is of great importance in dealing with large quantities of material. An exposure of larvae for two to three minutes to a temperature of 65°C. or for one minute to 70°C. may be considered ideal from practical point of view.

The only previous work which may be said to approximate to our experiments with naked larvae described above is that of Gough and Storey [1913]. These authors dipped seeds containing the larvae directly into water maintained at constant temperatures and found that dipping for two minutes in 55°C. or for five minutes in 50°C. was almost completely fatal. In these experiments larvae may be said to have attained the temperature of the hot water almost immediately after dipping, as the water penetrates into the infested and consequently damaged seeds at once. But it will be readily appreciated that these experiments are very different from ours, because of the actual immersing of the larvae in hot water, which apart from its effect due to temperature, influences the larvae due to partial or complete drowning. In all other experiments reported in literature, double seeds have been exposed to hot air and, as already shown, larvae inside the seed take 8—15 minutes to acquire the temperature of the hot air. It is obvious that when the exposures are less than 8—15 minutes, the larvae inside the seeds never attain the temperature of the surrounding air. That is why the actual temperature of the seed (at the exit of heating machines) is far lower than that prevailing inside the machine chamber.

TABLE II

Mortality in pink-bollworm larvæ exposed naked for different durations to different constant temperatures and saturation deficiencies

	Temperature (°C.)	Saturation deficiency (mm.)	Exposure	No. of larvæ		Percentage mortality	Remarks
				Exposed	Died		
A	45	3	12 hours .	30	17	56·7	Larvæ exposed on a glass plate
			24 ,, .	20	20	100	Do.
		14	12 ,, .	30	22	73·3	Do.
			24 ,, .	20	20	100	Do.
		32	12 ,, .	30	7	23·3	Do.
			24 ,, .	20	17	85·0	Do.
	50	3	2½ ,, .	30	30	100	Do.
			4 ,, .	30	30	100	Do.
		14	2½ ,, .	30	30	100	Do.
			4 ,, .	30	30	100	Do.
		32	2½ ,, .	30	22	73·3	Do.
			4 ,, .	30	30	100	Do.
B	55	..	10 minutes	12	0	0	Larvæ exposed on a copper plate
			30 ,,	30	16	53·3	Do.
			45 ,,	45	45	100	Do.
		..	3 ,,	12	2	16·7	Do.
		..	3 ,,	12	10	83·3	Do.
		..	5 ,,	12	11	91·7	Do.
			7 ,,	50	50	100	Do.
			10 ,,	20	17	85·0	Water bath*
			20 ,,	20	20	100	Do.*
	60	..	1 minute	74	57	77·0	Larvæ exposed on a copper plate
			3 minutes	37	32	86·5	Do.
			5 ,,	20	20	100	Water bath*
	65	..	1 minute	87	85	97·7	Larvæ exposed on a copper plate
			3 minutes	25	25	100·0	Do.
	70	..	1 minute	50	50	100·0	Do.

* With the exception of these experiments all others were conducted in the incubator (See 'Material and method')

INFLUENCE OF ATMOSPHERIC MOISTURE ON LARVÆ EXPOSED TO HIGH TEMPERATURES

The part played by the atmospheric moisture in causing larval mortality of *P. gossypiella* at high temperatures has not been investigated so far, although some observations on the effect of moisture on the viability of cotton seed [Richards, 1938] and on the rate at which heat is absorbed by the seed [Bredo, 1934] are available. In order to investigate this aspect of the problem, saturation deficiencies (S.D.) of approximately 3 mm., 14 mm. and 32 mm. were maintained in desiccators with various saturated salt solutions, at constant temperatures of 45°C. and 50°C., as detailed in Table III.

TABLE III

Relative humidities obtained at various constant temperatures by the use of saturated salt solutions

Temperature (°C.)	Saturation deficiency	Salt solution used	Relative humidity obtained (per cent)
45	3 mm.	K_2SO_4	97
	14 mm.	KCl	81
	32 mm.	$NaNO_3$	56
50	3 mm.	K_2SO_4	97
	14 mm.	KNO_3	84
	32 mm.	$NaNO_3$	62

Naked larvae were exposed as in previous experiments in dishes inside the desiccators. It may be added that the desiccators were placed in the incubator several hours before the larvae were introduced to ensure that the temperature inside the desiccator was the same as that of the incubator and that the required relative humidity had also come into equilibrium with the temperature. The results of these experiments are summarized in Table II.

It is interesting to note that while an exposure of 24 hours to 45°C. is completely fatal under S. D. of 3 and 14 mm., it is not so under 32 mm. Likewise, an exposure of 2½ hours to 50°C. is completely fatal under S. D. of 3 and 14 mm., but gives a partial mortality (73·3 per cent) if the S. D. is 32 mm. Thus, under comparatively dry conditions, the larvae resist high temperatures better; in other words, exposure remaining the same, higher temperatures are required to obtain complete mortality under dry conditions.

The practical importance of these findings is that other conditions such as temperature and exposure remaining the same, the heat treatment will be more effective during moist weather, or if the hot air of the oven is artificially charged with moisture. It must be stated here that according to Richards [1938] cotton seeds although resistant to dry heat lose their viability quicker under moist conditions. Therefore, in heat treatment both temperature and humidity conditions have to be suitably adjusted.

It would at first sight seem peculiar that a moisture-loving insect like *Platyedra gossypiella* should resist high temperatures better under dry conditions. Haroon Khan [1938], studying the ecology of pink-bollworm in the Punjab, showed that the pest is always serious in regions having mild and humid climate and negligible in hot and dry areas. Likewise, Squire [1937 ; 1940], investigating the causes underlying the diapause in this insect, concluded that 'short-cycle' or quick-developing larvae are found in nature as long as the environment and food are moist, but they begin to enter 'long-cycle' phase or hibernation when the conditions become unfavourable, *viz.* the environment and the food become dry. Thus according to him, lack of moisture is the chief factor producing diapause in this species. Conversely, the diapause is broken and larvae become active when they are placed in a moist atmosphere and are supplied with moist succulent food. Heavy and regular rainfalls during early period of the cotton crop are a feature of those countries where pink-bollworm is a serious pest, as these conditions are necessary to make the hibernating larvae active which in due course attack the new crop.

A close examination of these observations will indicate that resistance to dry heat does not go counter to the moisture-loving habit of the bollworm. Whatever the temperature, under dry conditions, aestivating larvae continue to remain inactive and it is a well-known fact that a quiescent stage of an insect can resist high temperatures better than its active stage. On the other hand, under moist conditions the diapause of the larvae tends to be broken, they become active and consequently succumb quicker to the influence of a given high temperature.

FATAL TEMPERATURES FOR LARVAE INSIDE INFESTED SEEDS

The results obtained from the exposure of naked larvae to heat, although of fundamental importance, are of only indirect value from practical viewpoint, as it is invariably the seeds which are exposed to heat for killing the hibernating larvae inside. All the previous workers, therefore, have tested the influence of high temperatures on larvae enclosed within the cotton seeds. In the following pages the data obtained by us on the influence of constant high temperatures, and of sun's heat on larvae infesting different varieties of cotton seeds are discussed.

Effect of constant high temperatures on larvae enclosed in double seeds

One to two hundred double seeds, containing in aggregate 50-90 living larvae, were put in a single layer inside incubators, running at constant temperatures (45°—70°C.). Before transferring to incubators, the seeds were kept at a room temperature of 35°—40°C., and were again put at this temperature after exposure to the constant temperatures referred to above. The seeds were then opened and it was quite easy to distinguish the larvae which had died a minute or so ago on account of heat treatment from those which were dead long ago due to other factors, before the seed was put in the incubators. The data regarding the effect of this treatment on larvae are summarized in Table IV. It was observed that the results obtained with water bath did not differ very much from those got with the incubator and are therefore also presented with necessary remarks in the same table.

These experiments indicate that for heat treatment, if seeds are brought from and taken to a room temperature of about 35°—40°C., an exposure of two hours to 50°C., 20 minutes to 55°C., 10 minutes to 60°C., 5 minuts to 65°C. or less than 3 minutes to 70°C. causes a partial larval mortality, while an exposure of a little over three hours to 50°C., 40 minutes to 55°C., 15 minutes to 60°C., 7—10 minutes to 65°C., or 3—5 minutes to 70°C. is completely fatal to the larvae.

In practice it will be better to adopt even longer exposure as the range of temperature at which the viability of seeds is affected is fairly higher as will be shown hereafter.

Effect of sun's heat on larvae inside double seeds

The sun's heat is the most important source of energy readily available without any cost. Its power to kill insects, particularly the pink-bollworm larvae inside seeds, is well known and it is a common practice with zemindars to expose their cotton seeds and other grains to sun's rays for disinfection. Richards [1938] stated that the maximum seed temperature recorded on a *pucca* floor during summer months in the United Provinces was 71°C. and a few minutes exposure to this temperature was sufficient to kill the larvae. On the other hand, on a *kucha* floor the temperature of seed seldom rose above 60°C. and for effective treatment it was necessary to keep the seeds on such floors for about ten minutes. Similarly, at temperatures between 52° and 56°C., 20 minutes exposure and at 50°C. an hour's exposure were necessary. Excepting these observations no detailed record of temperature variation from time to time of the soil and of the air and their effect on seeds are available. The intensity of the sun's heat, being often variable from minute to minute or day to day, depends on so many uncontrollable factors that it is difficult to appreciate its effect without an accurate and detailed record of all the conditions prevailing at the time.

Some of the important conditions which affect the intensity of sun's heat reaching an exposed material are :—

(*i*) The foremost factor affecting the intensity of sun's heat reaching the earth is its position and distance from the earth, which varies rapidly at different times of the day. This means that the exact geographical position of a locality and the time of the day for heat treatment are very important.

(*ii*) The amount of heat reaching the earth also depends on the condition of the medium through which it travels. Presence of dust and clouds in the way may almost completely cut away the supply of heat.

(*iii*) The velocity of prevailing wind and its humidity have also important influence.

(*iv*) Nature of floor on which an article is exposed plays an indirect but an important role in determining the rate of heating. Seeds spread in the sun on cloth or on *kucha* floor are exposed to much less heat from below than those spread on brick, cement, stone or metal floor.

TABLE IV

Effect of constant high temperatures on larvæ inside seeds of American cotton (289 F.)

Temperature (°C.)	Exposure	No. of larvae		Mortality (per cent)	Remarks*
		Exposed	Died		
50	2 hours . . .	33	27	81	
	3 hours 10 minutes .	30	30	100	
	4 hours . . .	52	52	100	Th.
55	20 minutes . . .	54	36	66·7	Inc.
	40 ,, . . .	32	32	100	,,
	20 ,, . . .	45	32	71·1	Th.
	40 ,, . . .	48	48	100	,,
	40 ,, . . .	43	43	100	,,
60	10 ,, . . .	38	29	76·3	Inc.
	15 ,, . . .	50	50	100	,,
	5 ,, . . .	22	15	68·2	Th.
	5 ,, . . .	48	10	20·8	,,
	7 ,, . . .	62	48	77·4	,,
	10 ,, . . .	13	13	100	,,
	10 ,, . . .	53	53	100	,,
61·6	10 ,, . . .	46	43	93·5	Inc.
	14 ,, . . .	42	42	100	
65	5 ,, . . .	34	13	38·2	,,
	10 ,, . . .	38	38	100	,,
	5 ,, . . .	112	97	86·6	Th.
	7 ,, . . .	50	47	94	,,
	7 ,, . . .	50	41	82	,,
	10 ,, . . .	51	51	100	,,
69·2	5 ,, . . .	49	14	29·4	Inc.
	7 ,, . . .	35	35	100	,,
70	5 ,, . . .	17	17	100	,,
	3 ,, . . .	19	19	100	,,
	3 ,, . . .	45	23	51·1	Th.
	3 ,, . . .	64	34	53·1	,,
	5 ,, . . .	58	58	100	,,
	5 ,, . . .	50	37	74	,,
	5 ,, . . .	45	33	73·3	,,

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* Th. = observations taken in the water bath ; Inc. = observations taken in the incubator

The present experiments were conducted at the Imperial Agricultural Research Institute, New Delhi, during June 1940 and March and May 1941 under as normal conditions as possible. Seeds were spread in a single layer on a *kucha* floor at different times of the day. It was observed that while the temperatures of the atmosphere at 10 A.M. and 5 P.M. were almost similar, those of the ground below were very different (Table V) and, therefore, different results were obtained. It was also evident from these experiments that when the shade temperature was between 38° and 40°C. and that of the soil in the sun between 50° and 55°C., under normal summer sunshine in June (Experiment No. 10), an exposure of seeds to sun on a *kucha* floor for 34 minutes gave complete larval mortality. Likewise, during hotter part of a similar day when shade temperature was 42°—43°C. and soil temperature in the sun between 60° and 65°C. (Experiment No. 14), an exposure of seeds for only about ten minutes was sufficient to kill all the larvae in double seeds. On the other hand during March when the temperature in shade was 26°—31°C. and soil temperature in the sun was between 34°—48°C. (Experiment No. 1), an exposure for even three hours was ineffiective to kill the larvae. A similar exposure on a hotter day in the same month (Experiment No. 3) was completely fatal. In another experiment (No. 7) during May, a cool day preceded by a small shower of rain, was selected and double seeds were exposed to the sun as usual. During the period of exposure there were wide fluctuations of temperature on account of the cool breeze and clouds appearing at times. An exposure of larvae inside double seeds for 9 hours on that day produced partial mortality (90 per cent). This experiment points out the wide fluctuations which sun's heat sometimes undergoes. A full day's exposure to sun in May (usually the hottest month) subsequent to rain and cool breeze may be useless, while only 10 minutes' exposure on a clear still day in June (Experiment No. 14) may give complete mortality. Thus it is not enough to lay down merely that seeds should be exposed for a certain period to sun in a certain month, without warning that the factors referred to above must be kept in view while selecting a day.

Sun treatment is, therefore, not a very dependable method of disinfection, particulary in the hands of illiterate and ignorant zemindars. Even in the hands of literate people who can take all the necessary precautions, such treatment will have to be followed by actual tests of larval mortalities, as this alone is the real criterion of effective treatment.

INFLUENCE OF NATURE OF SEED ON THE MORTALITY OF LARVAE UNDER HEAT TREATMENT

The nature of seed varies in different varieties of cotton. In some varieties the seed is small and compact, in others it is larger but more soft. Again, some are fuzzy while others are bare. Accordingly, when exposed to heat treatment, they offer different degrees of protection to the larvae lying within. Furthermore, as already pointed out, the quantity of moisture in the seed also greatly affects the rate at which it gets heated.

Two common varieties of cotton seed, *viz.* American (289 F) and *desi* (Mollisoni) were used for comparison and the results are summarized in Tables IV and VI. The seeds of American variety were large and hairy, those of

TABLE V

Larval mortality inside double seeds of cotton exposed to sun during March to June at Delhi

Experiment No.	Period of Experiment	Time of the day	Exposure	Temperature range °C.				Mortality per cent		Remarks
				Shade	Soil	Sun				
						Black bulb	White bulb	*Desi*	American	
1	March	9 A.M.	3 hours	26·0—31·0	34·0—48·0	38·0—60·0	30·0—41·0	0	0	Light clouds appearing every now and then
2	,,	,,	1 hour 45 minutes	30·0—34·5	38·0—53·3	47·7—65·5	35·0—46·2	69	72·2	
3	,,	,,	3 hours	30·0—37·2	38·0—59·0	47·7—67·2	35·0—49·0	100	100	
4	,,	2-20 P.M.	15 minutes	39·0—39·0	54·5—56·8	48·0—67·5	40·3—50·0	95	97	
5	,,	,,	30 ,,	39·0—39·5	54·5—56·8	48·0—68·0	40·3—49·8	100	100	
6	May	8-22 A.M.	5 hours	27·0—31·0	31·0—49·0	42·2—61·1	32·2—43·8	69	61	A cool day preceded by light shower of rain
7	,,	,,	9 ,,	27·0—33·5	30·0—54·5	40·0—67·2	32·2—46·1	90	93	
8	June	9 A.M.	35 minutes	35·0—35·7	43·6—47·0	49·0—61·0	39·5—45·5	0	...	
9	,,	,,	60 ,,	35·0—36·2	43·6—50·5	49·0—63·0	39·5—47·0	47	...	
10	,,	10 A.M.	34 ,,	38·7—40·0	49·5—55·3	62·0—67·0	47·0—51·0	100	...	
11	,,	5 P.M.	10 ,,	41·7—41·4	54·7—54·8	51·0—61·0	41·0—47·5	18	...	
12	,,	,,	20 ,,	41·7—41·2	54·7—54·8	51·0—63·0	41·0—49·0	53·7	...	
13	,,	1 P.M.	5 ,,	42·2—41·7	60·0—64·3	57·0—68·0	44·5—52·0	98	...	
14	,,	,,	10 ,,	42·2—42·7	60·0—65·7	57·0—73·5	44·7—54·0	100	..	

the *desi* variety were small and bare. But the texture of *desi* seeds was much more compact than that of the American variety.

From a comparison of Tables IV and VI it will be noticed that although there is not very marked difference in the mortality of larvae inside the two varieties of cotton seeds, there is throughout a somewhat higher mortality among larvae inside the American variety as compared with those inside the *desi* variety. Thus, for instance, while an exposure of two hours to 50°C. caused 81 per cent larval mortality in American seed, an exposure of two and a half hours to the same temperature caused 72·7 per cent mortality in the case of *desi* seed. Likewise, an exposure of 20 minutes to 55°C. caused 66·7 per cent mortality in the American, against 21·1 per cent in the *desi* variety and so on. However, as these differences are not very great, it will be quite effective to recommend for general adoption somewhat longer exposures or slightly higher temperatures to cover the varietal differences indicated above. This should be quite feasible since there is fair margin of safety between heat exposures fatal to larvae and those injurious to the viability of the seed.

EFFECT OF HIGH TEMPERATURE ON THE VIABILITY OF COTTON SEED

In order to determine the effect of different degrees of heat on the viability of cotton seed, 100 apparently sound seeds of two varieties were selected and exposed for definite periods to a number of constant temperatures. They were then sown in moist sand and kept for germination at room temperature of 35°—40°C. Almost all the viable seeds germinated within a week and their percentage was noted. The results are summarized in Table VII. In the case of the control experiments comprising four tests with Mollisoni variety and two tests with American variety, it will be noticed that unfortunately the original viability of the seeds was not very high, only about 50 per cent of *desi* and 24 per cent of American seeds being viable. This range of percentage viability is practically maintained after almost all the heat exposures tried. Thus, briefly speaking, the viability of seeds is not materially lowered after an exposure of 30 minutes to 65°C., or 20 minutes to 75°C., or 10 minutes to 80°C. This indicates that there is a fair margin of safety between the heat treatments necessary to kill the bollworm and those at which the viability of the seeds is adversely affected.

CONCLUSIONS AND SUMMARY

The method of controlling the pink-bollworm by preventing the 'carry over' of the hibernating larvae found inside the harvested seed by suitable heat treatment has been followed in some countries and recommended for adoption in certain parts of India. Yet little accurate data on lethal temperatures and humidities for the bollworms themselves (outside the cotton seed) and for the seed are available under Indian conditions. At the request of the Department of Agriculture, United Provinces, this investigation was taken up in 1940 and the results of the work carried out so far are presented in this paper.

TABLE VI

Effect of constant high temperatures on larvae enclosed in double seeds of desi *cotton* (*Mollisoni*)

Temperature (°C.)	Exposure	No. of larvae		Mortality (per cent)	Remarks*
		Exposed	Died		
45	12 hours	48	0	0	Inc.
	24 ,, ...	53	47	88·7	,,
	36 ,, ...	..	..	..	
50	2½ ,, ...	66	48	72·7	Inc.
	4 ,, . .	58	58	100	,,
55	20 minutes	38	8	21·1	,,
	40 ,, ...	5	5	100	,,
	40 ,, ...	50	50	100	,,
60	10 ,, ...	35	5	14·3	,,
	15 ,, ...	15	15	100	,,
64·4	5 ,, ...	40	14	35	,,
	10 ,, ...	51	51	100	,,
65	10 ,, ...	1	1	..	
	10 ,, ...	13	13	81·1	Th.
	10 ,, ...	56	47		,,
69·2	5 ,, ...	50	12	24	Inc.
	7 ,, ...	12	12	100	,,
70	3 ,, ...	27	16	59·2	Th.
	5 ,, ...	28	14	50	,,

* **Inc. = observations taken in the incubator**; Th. = observations taken in the **water bath**

TABLE VII

Effect of high temperatures on the germination of cotton seed

(100 seeds sown in each case)

Temperature (°C.)	Exposure	Percentage germination	
		Desi	American
45	12 hours	52	. .
45	24 ,, ...	53	. .
50	4 ,, ...	54	. .
50	6 ,, ...	43	. .
55	1½ ,, ...	58	. .
60	30 minutes	65	. .
65	10 ,, ...	43	34
65	15 ,, ...	38	28
65	30	52	26
70	5 ,, ...	49	15
70	10	37	30
70	20	42	26
75	5 ., ...	42	21
75	10 ., ...	40	16
75	20 ,, ...	38	13
80	3 , ...	57	23
80	5	59	24
80	10	47	27
Control	. . . .	54	. .
,,	. . . .	53	. .
,,	. . . .	48	20
,	. . . .	45	28

Hitherto almost all the workers have subjected bollworms enclosed in cotton seeds to various temperatures. It is obvious that the value of such results is limited as the effect of these exposures would vary widely with the temperature and moisture content of the environment in which seeds remain before and after treatment, the texture and fuzziness of the seed, the thickness of layer in which seeds are passed through the heating machine, etc. Thus the heat-tolerance of naked larvae taken out of the seeds which is of fundamental importance in the study of heat treatment, as a control measure, has been investigated for the first time.

These experiments have shown that naked larvae undergo complete mortality when exposed for 24 hours to 45°C., 1—2½ hours to 50°C., 7—10 minutes to 55°C., five minutes to 65°C. or one minute to 70°C. If instead of naked larvae the cotton seeds containing larvae are treated and are brought from and taken to a room temperature of 35°—40°C., in a thin layer, an exposure of a little over three hours to 50°C., 40 minutes to 55°C., 15 minutes to 60°C., 7—10 minutes to 65°C., or three to five minutes to 70°C. is completely fatal to larvae within the seeds. It may thus be concluded that from practical point of view, where time factor is of considerable importance in dealing with large quantities of material, the exposure of seeds to heat should be so regulated in reference to the initial and final seed temperature and the nature of seed, etc. that the larvae themselves inside the seeds are at a temperature of 65°—70°C. for one to two minutes.

The part played by atmospheric moisture in determining larval mortality at different high temperatures was hitherto little explored. We have now determined that under relatively dry conditions the larvae resist high temperatures better and, therefore, longer exposures would be required to ensure complete mortality. For instance, while an exposure of seed for 24 hours to 45°C. is completely fatal to larvae if the saturation deficiency of air is 3—14 mm., it is not fatal if the saturation deficiency is 32 mm.

Experiments on the protection afforded by the variety of cotton seed to the larvae inside them during heat treatments were conducted only on two varieties, *viz.* a *desi* variety (Mollisoni) and an American variety (289 F). It has been found that although the difference is not great, the heat treatment remaining the same, there was always higher mortality among larvae inside American seed as compared to those inside *desi* seed.

The viability of cotton seed is not affected materially up to an exposure of about 30 minutes to 65°C. or 20 minutes to 75°C. or 10 minutes to 80°C. This shows that there is a fair margin of safety between heat exposures fatal to larvae and those injurious to the viability of the seeds. It must be pointed out that in practice the seeds after coming out of the hot machine retain heat for some time, particularly if they are put into sacks immediately after treatment and this period must be kept in view while prescribing temperature and exposure.

The technique of heat treatment is discussed. It is experimentally shown that heat takes a considerable time to penetrate through a layer of cotton seed. For instance, when seeds were transferred from a room temperature of about 36°C. to a chamber at 68°C., the seeds only less than half an inch below the surface took seven to eight minutes to reach within a degree of the chamber temperature. These experiments emphasize that during heat treatment, the seeds should be exposed in a very thin layer, the entire quantity should be kept well stirred constantly and the chamber-air above the seeds must also be kept in motion.

The effect of sun's heat as a method of killing larvae inside seeds is discussed. The intensity of sun's heat is so markedly affected by factors beyond human control that a warning is given here against laying down any dogmatic principles about the disinfection of seeds by exposing to sun. For instance the heat reaching an exposed material from sun depends not only on its diurnal position and distance from earth but also on the condition of the medium through which heat travels (*e.g.* the presence of dust, clouds, etc.), the velocity and nature of prevailing winds, the nature of floor on which the seeds are spread, etc. Results of some experiments accompanied with records of air temperature in shade, and in the sun (black and white bulb temperatures), soil temperature, etc. are presented, which show that an exposure of infested seed to sun for 9 hours during the hottest part of the year (May) may not be completely effective if the day, although otherwise clear, follows a shower of rain giving rise to cool breeze. On the other hand, under ideal conditions of heat transmission only half an hour's exposure of infested seed to sun during a comparatively cool month of March may give cent per cent mortality of larvae. At any rate, the factors on which the success of sun heat as a control measure depends are so variable that every individual exposure must be followed with an actual test of mortality among larvae inside the treated seed before the particular consignment can be said to have been effectively treated.

REFERENCES

Bredo, H. J. (1934). *Bull. agric. Cong. belge.* **25,** 250-70
Gough, L. H., and Storey, G. (1913). *Agric. J. Egypt* **3,** 73-93
Gough, L. H. (1916). *Bull. Minist. Agric. Egypt* **6,** 1-18
Haroon Khan, M. (1938). *Indian J. agric. Sci.* **8,** 191-214
Mohammad Fuad-al-Gammal (1940). *Bull. Minist. Agric. Egypt* **150**
McDonald, R. E., and Scholl, G. J. (1922). *Bull. Tex. Dep. Agric.* **71,** 138
Richards, P. B. (1938). *Indian Cent. Cott. Comm., First Conference of Scientific Research Workers on Cotton, 1937,* pp. 22-6
Squire, F. A. (1937). *Trop. Agric. Trinidad* **14,** 299-301
———— (1940). *Bull. ent. Res.* **30,** 475-81
Storey, G. A. (1915). *Agric. J. Egypt* **4,** 115-24
———— (1916). *Bull. Minist. Agric. Egypt* **11,** 1-10

THE LIFE-HISTORY, BIOLOGY AND ECOLOGY OF THE APPLE ROOT BORER, *LOPHOSTERNUS HUGELII* REDTEMBACH, IN KUMAUN

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(With Plate LXVI)

LOPHOSTERNUS HUGELII Redtembach is an important pest of apple tree (*Pyrus malus*) in Kumaun. The larva is a long, thick, yellowish white grub. It attacks the roots and occasionally the portion of stem that remains in the ground. It feeds either by boring or by girdling around them. In most cases all the main roots are severed from the base and consequently the tree dies.

It has not been recorded as a pest of fruit trees in Kashmir, Baluchistan and Assam*. It also does not appear to have been recorded as such in any other country. Fletcher [1917] has given a brief account of its attack on apple trunks and roots in Kumaun. Beeson [1919] has mentioned *Quercus ilex* and *Quercus incana* as its food plants. In Kumaun, the author has observed the larva feeding mostly on dead stumps and roots of *Quercus incana* and on both living and dead roots of apple trees. Occasionally, it has also been found on dead roots of other forest trees and shrubs, such as *Pinus longifolia*, *Rhododendron arboreum*, *Pieris ovalifolia* and *Rubus flavus*. Among the fruit trees other than apple, the roots of pear (*Pyrus pashia*), peach (*Prunus persica*), cherry (*Prunus puddum*), and apricot (*Prunus armeniaca*) have also very rarely shown signs of damage by this borer, but in confinement it feeds on roots of all fruit trees grown in Kumaun hills. The details of the life-history of the insect has not been worked out so far. Stebbing [1914] seems to have taken some other larva for *L. hugelii*, as was also pointed out by Beeson [1919]. The account of its life-history as given by him has not been confirmed by the writer. The beetle was originally described in 1848 and re-described by Gahan [1906]. A technical description of the larva is given by Beeson [1919] to which some further descriptive notes are added by Gardner [1927].

Excepting these few details, no extensive work has been done anywhere either on its life-history or biology. A systematic work was, therefore, undertaken at this Station to study these points in detail. The work had to be spread over a number of years as the usual life cycle of the borer occupies four years. In addition to this, responses of the newly hatched and grown up borers to different environmental conditions have been studied with a view to devise control measures. Experiments on large scale were carried out under laboratory conditions for three consecutive years to see the effect of various soils and moisture contents upon oviposition response, development of egg and survival period of young grubs. Observations have also been made on the food materials of the grub, its habits inside ground and the effect of cultural operations on the development of egg and newly hatched grub.

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* Private communications from the Directors of Agriculture

DISTRIBUTION IN NORTHERN INDIA

Gahan [1906] recorded it from Kashmir, N.-W. Province, Punjab and Assam. Beeson [1919] has in this connection mentioned Bashhar State, Mussoorie, W. Almora, Naini Tal and Siwaliks. It is very common in almost every orchard in Almora and Naini Tal districts, mostly on apple roots and dead oak stumps.

ECONOMIC STATUS OF THE PEST IN KUMAUN

It is a very serious pest of apple trees in these hills. As will be seen from the account given below, hundreds of apple trees are killed and thousands are rendered more or less unfit for bearing every year. In some portions of the orchards, the trees attacked may exceed 40 per cent. The amount of damage caused by this pest, recorded for a portion each of two orchards at Ramgarh and Chaubattia for the year 1931 and 1937 respectively, is given in Table I.

TABLE I

Number of apple trees attacked and killed by the apple root-borer

Name of orchard	No. of trees examined	No. attacked	Per cent attacked	No. killed	Per cent killed	Year of examination
Portion of an orchard at Ramgarh	1,081	451	41·7	59	5·36	1931
Portion of Govt. orchard, Chaubattia	488	82	16·8	28	5·74	1937

In every orchard certain portions are more susceptible to borer attack than the rest. Apparently the trees on dry sandy soil with little or no humus suffer most. Such soils are generally met with on ridges and steep slopes. Number of apple trees found attacked and those that were actually killed in different portions of the Government Orchard, Chaubattia, in the year 1936-37 are given in Table II. The orchard is situated on the Ranikhet, Chaubattia hill, at an elevation of 6,100—6,700 feet and is surrounded on all sides by oak and pine forests. There are hundreds of dead oak stumps all over the orchard and these afford a very suitable breeding place for the pest.

It will be seen from this table that the intensity of attack varies very much in different portions of the orchard.

TABLE II

Percentage of apple trees attacked and killed by the borer during the year ending 31 March 1937 in the Government Orchard, Chaubattia (in different blocks)

Blocks No.	Soil profiles			Percentage of trees attacked	Percentage of trees killed
	Sandy	Clayey	Sandy loam		
A . . .	16	6	5	16·20	5·74
B . . .	12	7	1	13·29	2·11
C . . .	3	5	4	3·47	1·04
E . . .	6	5	7	3·33	0·91
F . . .	3	2	6	2·11	1·41
G . . .	3	4	8	2·21	1·33
H . . .	8	9	10	4·71	0·72
I . . .	4	4	7	5·71	3·19
J . . .	8	6	6	3·83	0·91
K . . .	5	2	2	1·15	0·38
M . . .	4	4	2	0·28	0·28
N . . .	7	12	6	1·40	0·70
O . . .	1	1	2	1·25	0·23
Q . . .	4	6	13	2·22	. .
R . . .	2	10	12	0·58	. .
S . . .	16	14	9	6·23	0·74

Effect of the borer attack on apple trees

All the trees attacked by the borer are not affected to the same extent. Young tree having only one main root is killed outright, but a big, vigorously growing tree having many thick roots may not feel the attack to start with, provided the borer attacks only one root and confines itself to it. Young and small trees suffer most. Such trees will either die or remain very unhealthy, being suported by a few rootlets which are generally given out from the base when the main roots are cut off. Age, height and condition of all the attacked trees in the Chaubattia orchard were noted in the year 1934-35. The results summarized in Table III very clearly indicate that there is comparatively greater mortality in young and small trees.

TABLE III

Effect of the borer attack on apple trees of different ages and sizes

Condition of attacked trees	No. of trees	Average age in years	Average height in feet
Apparently unaffected	18	11·45	5·3
Slightly affected	24	9·96	4·2
Affected	44	10·4	3·84
Severely affected	46	9·6	3·44
Dead	34	7·3	3·7
Total .	166		

DESCRIPTION OF DIFFERENT STAGES OF THE INSECT

As has already been pointed out, the adult and full-grown larvae have been described by Gahan and Beeson respectively.

The larva has been observed here from the time of hatching till pupation, *i.e.* for about three years and nine months. The changes occurring in its development at particular times are briefly described in this paper.

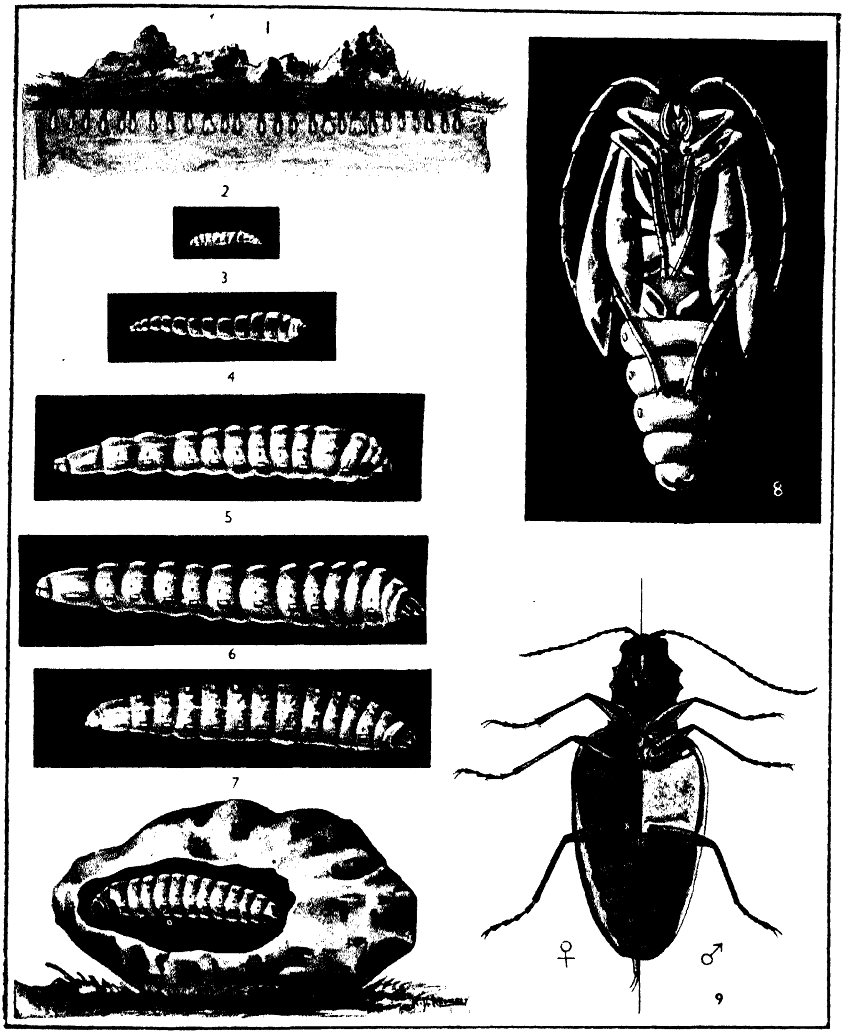
Egg

The eggs (Plate LXVI, fig. 1) are elongate-ovoid, yellowish white, measuring from 2·8 mm. to 3·2 mm. in length and from 0·8 mm. to 1 mm. in breadth. One end is slightly pointed and the other, which breaks open at the time of hatching, rounded. They are hard to withstand ordinary pressure and can easily be transferred from one soil to another several times by means of a camel hair brush. Irregular parallel ridges run longitudinally all over the outer surface and these under high power appear dotted. They cross one another at several places to form hexagonl areas of different sizes.

Different larval stages

The newly hatched larva is creamy white, thickset near the thorax ; light brown erect hairs all over the body. Length of an average-sized larva 3·5 mm., thickness 1 mm. near the thorax. In about four months it becomes 6—12 mm. long and body colour changes to reddish white. There are vast differences between the sizes of the different larvae of the same age. Thus the lengths of different larvae vary from 8 mm. to 15 mm. in the seventh month and from 12 mm. to 24 mm. in the ninth month. Up to about ten months after hatching the body colour remains reddish white, but after that the reddish tinge gradually disappears. In the 14th month, when the lengths of different larvae vary from 18 mm. to 31 mm., the general body colour becomes dark brown, but the ridges of every segment remain white. There is no marked difference in

Lophosternus hugelii



1. Eggs laid in the ground ($\times\frac{1}{4}$); 2. Newly hatched grub (nat. size); 3. One year old grub ($\times\frac{3}{8}$); 4. Two-year old grub ($\times\frac{5}{16}$); 5. Three-year old grub ($\times\frac{5}{16}$); 6. $3\frac{1}{2}$-year old grub ($\times\frac{5}{16}$); 7. Grub inside pupating chamber ($\times\frac{1}{4}$); 8. Pupa ($\times\frac{3}{4}$); 9. Ventral view of both sexes ($\times\frac{1}{2}$)

the body colour in the following 11 months, but the larva goes on growing all through the period. In the end of the second year, larvae are from 74 mm. to 100 mm. long. There is very slight increase in the body after this period, but the body colour gradually changes to yellowish white. In the beginning of the fourth year the body begins to contract and yellowish tinge goes on deepening till 42nd month after hatching when the borer leaves the apple root and makes an earthen cell in the ground near the root to pupate inside it. Inside this earthen cocoon there is no change outwardly in the body for the first three months except that the body goes on contracting and a watery fluid is secreted all the time, and this makes the inner surface of the earthen cocoon very clean and uniform. At the end of these three months, the grub is only about 38 mm. long with a transverse orange-red line on its head. Actual pupation begins after this, i.e. in the end of May and adult may emerge any time in June and July after the first shower of rain (Plate LXVI, figs. 2-9).

Technical description of the mature larva

Beeson [1919] has described the larva and Gardner [1927] provides some additional information. The following summary is given to identify the larva.

Body straight, more or less cylindrical, tapering gradually posteriorly and gradually enlarged in the thoracic region. Head large, deeply embedded in thorax, depressed. Labrum free and distinct. Ventral mouthparts not retracted, the submentum not continuous with prothoracic skin (i.e. the anterior ventral margin of the head capsule is visible). The dorsal surface of prothorax with a large transverse trapezoidal area and quite different in appearance from the ventral surface. Spiracles with oval peritremes (family characters).

The ventral surface of the head with a smaller anterior foramen in addition to a larger posterior foramen (in other subfamilies there is no anterior foramen). Mandibles with the distal cutting edge oblique, the lower extremity more acute (distinction from Cerambycinae). Head only slightly longer than wide, emarginate posteriorly. Legs small but quite distinct. Dorsal ambulatory areas of abdomen with two, the ventral with one, transverse impressed lines. Caudal extremity without points or spines (sub-family characters).

Antennae with three segments, the apical one very small (note that a basal connecting membrane is not a segment). The anterior (epistomal) margin of the head forms a flat rather short projection, with angulate extremities, over the whole clypeus ; behind that is a moderately raised but distinct transverse ridge which is at most feebly depressed medially. The head has a quite strong posterior emargination. There are no distinct ocelli. The pronotum is irregularly rugulose (generic characters).

The larva is yellowish white with the exposed part of head and mandibles black, prothorax reddish anteriorly and laterally. The skin smooth with sparce and very inconspicuous hairs. Length up to about 106 mm.

The pupa

The pupae are of various sizes, measuring from 18 mm. to 31 mm. in length. It is of exarate type, the head strongly bent downwards and the abdomen sharply tapering towards the caudal end. From the time of the first appearance of the organs of locomotion, the colour gradually changes from yellowish white to chestnut red.

The adult (beetle)

Gahan [1906] has described ***Lophosterums*** and has also given the main characters of ***hugelii*** to distinguish it from other species of the genus. The adult found and studied in Kumaun conforms to Gahan's description except in a few minor details like the variation in body lengths, etc. A brief description of the beetle, embodying its important generic and specific characters, is given below :

Male.—26—58 mm. long, chestnut red in colour, the head and prothorax darker than elytra. Head elongated behind the eyes, short in front, strongly and closely punctured. Mandibles long, curved downwards, crossing when closed, their inner edges sharp. Palpi long, last joint gradually widened towards the extremity. Antennae a little shorter than the body, 11-jointed, first joint not reaching beyond the hind margin of the eye, third to tenth acutely produced at the apex on the anterior side, third with sharp anterior edge near which it is finely and very closely puntualate. Prothorax transverse, convex above, its lateral edge oblique and denticulate in front, produced into a spine at the middle into another spine near the front margin and sharply angulated near the base. Pronotum finely and closely punctured in front and for some distance back along each side of the middle line, more strongly punctured towards the sides, its hind angles more or less obtuse. Elytra more than twice as long as broad, slightly narrowed behind, more or less round at the apex, rugulose, the ridges finely punctured ; each with two or three feebly raised obtuse costae. Hind breast covered with a tawny coloured silkly pubescence. Legs long, tarsi elongated, the first joint as long as the second and third together, third joint bilobed, the lobes rounded at the end. Last ventral segment sinuate at the apex.

Female.—Head and mandibles shorter. Antennae hardly reaching to the middle of the elytra, more slender and less strongly serrate than in the male, the joints from the fifth only, acutely angulate at the apex. Hind breast bare of pubescence. Last ventral segment with rounded hind margin.

Out of the 100 males the average weight of the ten biggest ones was 3·75 gm. and that of the ten smallest ones 0·62 gm., i.e. the biggest beetles are about six times heavier than the smallest ones. There is similar variation among the female beetles also.

LIFE-HISTORY

Emergence

Emergence of adults from the soil starts at the break of monsoon about the end of June and lasts for about a month. Early showers during the first week of June, preceded by hot, sunny days, bring forth some beetles earlier, but occasional rains in April and May and low temperature in June delay emergence. In exceptional cases when the temperature in the summer months remains below normal throughout with frequent showers of rain, the pupation period is very much prolonged. As a result of this only a few beetles emerge. Such a case was observed in 1936. Beetles of both sexes are attracted to light, but collections at light contained mostly males. Out of 224 beetles collected, only 14, i.e. 6·25 per cent of the total were females, *Habits of the beetle*

During the day time beetles have never been seen on the wing. In the orchard they remain motionless under grass in dark holes. Inside the cages, if there be no grass, they make small holes in the soil along the sides of the cages just enough to hold their bodies. They do not move about during the day unless disturbed and then they search their mate and begin to copulate. The female goes on depositing eggs while moving. They move about freely during night and fly to the nearest strong light. Beetles do not feed and they are short lived. Copulation and egg-laying begin soon after emergence. The male dies only a few days after, while the female dies after depositing all its eggs.

Oviposition

Soon after emerging from the ground the beetles seek their mates. The male follows a female and rides over her, in most cases from behind but occasionally from the sides also. Holding the female by its forelegs at the hind margin of its prothorax, it extends its pygidium and inserts the aedeagus into the female's genital aperture. The female may remain stationary while the copulation is going on or move about with the male on its back. The male, throughout the process, moves its legs backwards and forwards. The female may copulate several times with the same or different males every day for the whole of its life of about 16 days. Beetles can be seen copulating at any time during the night, but during the day they seek mate only when disturbed from their hiding places.

The female starts egg-laying a few hours after copulation and goes on copulating and laying eggs daily for the whole of its short life. When about to lay eggs, she moves about on the ground in search of suitable place, dragging behind her extended ovipositor. On finding a desired place, she stops and thrusts her ovipositor into the soil and deposits one or more eggs to a depth of about 8 mm. She then moves on to some other place and lays eggs similarly. Unlike many other insects, the female does not lay eggs particularly on or near the food material of the young larva. Generally, eggs are laid singly, but batches of two, three and four eggs have also been found. When more than one egg is laid at the same time, these remain attached to one another longitudinally by means of a gelatinous substance. Very often small particles of soil are found adhered to the eggs.

Observations made on the egg-laying capacity of the female and the duration of egg-laying period have shown that the average number of eggs laid by one female is about 300 and the average egg-laying period 16 days.

Results of the experiments on the effect of various soils and moisture contents upon oviposition response carried out at this station have indicated that 20—40 per cent saturation of soil is most suitable for egg-laying in all the three kinds of soils, viz. clayey, sandy and organic and that sandy soil is preferred by the beetle for this purpose.

Hatching

Laboratory experiments carried out to study the different aspects of hatching showed that in normal cases about 80 per cent of the eggs hatch.

The hatching continues for about 40 days, but about 70 per cent of the eggs hatch within 29 days. There is, however, a definite correlation between the moisture content of the soil and hatching. The most suitable saturation for hatching was found to be 20—40 per cent. Below and above this range of saturation, the percentage of hatch goes on decreasing.

Habits of the grub

After hatching young grubs move about on the ground at random. Observations showed that they do not possess food direction sense and hence very few of them succeed in reaching the roots. The newly hatched grub can live in any soil with or without any root for over 20 days provided the soil contains the right amount of moisture (20—40 per cent saturation). If during this period young larva happens to come in contact with some root, it attaks it ; otherwise it dies in the soil. It does not seem to feed on roots daily, for, at times it has been observed lying in the soil near the root for several days. When a root has all been eaten away, the grown-up borer moves about very slowly inside the ground, not necessarily in the direction of another root. It has been observed to survive in orchard soil without roots for about three months and, if within this period a suitable root is reached, it is attacked but, unless such root is very near, it is very likely that the borer after leaving a root dies before it can get on to another. Of the grubs hatching out every year, a few go on feeding on roots for about 3½ years, after which they leave the roots and prepare pupating chambers of particles of soils near the attacked roots.

Of the 46 borers found on or near the apple roots, 45 were within 3—10 in. depth and 77 per cent of these were confined between 4—8 in. As regards the distance from the base of the tree, one was found 30 in. away and the rest were all within 12 in. of it ; 56 per cent of the total number were found exactly at the base.

Observations made on the effect of different soils and moisture contents on survival period of young grubs have indicated that in all soils the mortality of grub is accelerated by the increase of moisture above 40 per cent saturation.

From a review of the results of the three years' (1937-39) observations on the food material of young grubs, it may be concluded that young grubs after hatching feed on all kinds of organic matter present in the soil, but farmyard manure, leaf-mould and well-decomposed orchard vegetation shorten their lives as they can live in soil, practically free from organic matter, for a longer period.

Pupation

Pupation invariably takes place inside the earth cell prepared by the grub.

First of all the body contracts and there is some watery secretion. The head then slightly bends downwards and faint red lines gradually appear on the thorax. After about three months' rest inside the cell the legs, antennae and wing-pads begin to appear. The final stage is reached about the middle of June in normal years, but the beetle does not emerge from the ground before the first heavy rainfall.

Survival of the borer to maturity

Under artificial conditions very few borers were reared to maturity. Out of 455 newly hatched grubs kept in breeding cages in 1932, only one survived for about 3½ years and died just when it had started pupating, and of the 660 kept under similar conditions in 1935, only five survived till March 1938. One of these assumed adult stage in July 1938 and three in July 1939. The remaining one died sometime before November 1938. Observations have been made on various occasions on the survival of the grubs in nature and every time it was found that most of them died before reaching maturity. One female beetle lays 300 eggs on average and it has been observed for several years that the percentage of trees attacked by the borer remains almost constant in every orchard in Kumaun. If it is assumed that equal number of males and females are produced in nature, it means that only two out of 300, i.e. 0·6 per cent reach maturity.

EFFECT OF MOISTURE ON THE NEWLY HATCHED GRUB

Observations on the effect of different soil saturations on the survival of the grub have indicated that the young borer thrives best in soils with 20—40 per cent moisture contents. It does not do well in very wet soils. The present experiment was carried out to see how long the borer can live in dry soil. Six newly hatched grubs were liberated on each of the various sorts of dry and moist soils and their survival period noted. The results are briefly summarized in Table IV.

TABLE IV

Effect of moisture on newly hatched borers

Name of material	Date and time of liberation	Date and time of dying	Average survival period
Moist garden soil (20—40 per cent saturation)	27-7-35 10 A.M.	19-8-35	23 days
Sun-dried garden soil	27-7-35 10 A.M.	27-7-35	7 hours
Moist subsoil (20—40 per cent saturation) .	13-8-35 10 A.M.	5-9-35	23 days
Sundried subsoil	13-8-35 10 A.M.	13-8-35 4-30 P.M.	6½ hours

It is clear from Table IV that moisture in the soil is necessary for the life of the young borer.

EFFECT OF TEMPORARY SHORTAGE OF SOIL MOISTURE

The development of eggs

To determine the effect of temporary drought on hatching of eggs, six eggs of different ages were kept in each of the ten glass dishes containing sun-dried soil on 27th July 1935. The soils of five dishes were moistened to about 30 per cent saturation after two days and those of the remaining after five days. The number of larvae hatching out in every dish was noted down. The results are tabulated in Table V.

TABLE V

Effect of temporary shortage of soil moisture upon the development of eggs of different ages

Cage No.	Number of eggs	Age of eggs	Time of their remaining in sun-dried soil	Average No. of days taken in hatching	Number hatched	Percentage of hatching
1 . . .	6	Fresh .	2 days .	26 days .	3	50
2 . . .	6	6 days	,, .	33 ,, .	4	67
3 . . .	6	12 ,,	,, .	No hatching	..	0
4 . . .	6	18 ,,	,, .	36 days .	6	100
5 . . .	6	23 ,,	,, .	28 ,, .	6	100
1 (*a*) . . .	6	Fresh .	5 days .	26 ,, .	3	50
2 (*a*) . . .	6	6 days	,, .	34 ,, .	4	67
3 (*a*) . . .	6	12 ,,	,, .	No hatching	..	0
4 (*a*) . . .	6	18 ,,	,, .	30 days .	6	100
5 (*a*) . . .	6	23 ,,	,, .	28 ,, .	6	100

Although there were only six eggs in each dish, it will be quite fair to draw certain conclusions from this experiment as the results obtained are absolutely similar in both cases. It is clear that temporary drought on or about twelfth day after laying is fatal, but it does not seem to affect the younger and older ones much.

The experiment was repeated in 1937 and the data, which are briefly expressed in Table VI confirmed the results of the previous observations.

TABLE VI

Effects of temporary shortage of soil moisture on the development of eggs

Serial No.	Age of eggs on 19-7-35	No. liberated	Time of their remaining in sun-dried soil	Condition of eggs on 22-7-37	Number hatched
1	Newly laid .	23	19 to 22 of July	Looking healthy	23
2	8 days old .	16	Do. .	Shrivelling .	1
3	14 ,, ,, .	9	Do. .	Do. .	**Nil**
4	21 ,, ,, .	11	Do. .	All eggs hatched	11

Newly hatched grub

The object of the experiment was to see if a temporary drought affects the young borer grub ; for, an occasional dry spell during rainy season is not uncommon. Four cages were prepared, two with a 2-in. layer of moist soil (20—40 per cent saturation) at the bottom and 2-in. layer of sun-dried soil at the top. The other two with the dry layer of soil at the bottom and the moist layer of soil at the top. Twenty young grubs were liberated in each cage at all the four different positions.

The results, summarized in the appendix, do not show any indication of the grubs moving in any particular direction. Some of them by chance happen to reach moist soil below, but quite a few come to the surface in dry soil and die.

EFFECT OF DIGGING THE GROUND ON THE EGG AND NEWLY HATCHED GRUB

Eggs are only slightly affected by the disturbance in the soil caused by cultural operations such as digging and hoeing. A piece of ground in which hundreds of eggs were laid was dug up to expose the eggs to the surface but only one egg was exposed. Disturbing the position of the egg does not affect its development so long as it remains in moist soil. In the laboratory thousands of eggs have been removed from the soil and transferred to various cages but hardly any of them was injured. An attempt was also made to scrape off an uniform layer of about ½-in. from the upper surface of the ground so that all the eggs could be removed from the ground and destroyed. But as in the rainy season the ground remains wet and grass grows everywhere, such layer could not be scraped off. The egg-shell is hard to stand ordinary handling and shaking. In laboratory they were taken out from soil, counted, and replaced in the soil without least injury to any of them. All that was required for the development of eggs was that they should remain in moist soil at 78°—92°F. These observations show that digging or hoeing of the ground is ineffective for destroying the eggs and besides, eggs are also laid in banks which offer almost as much space for egg-laying as the terraces which for other reasons should not be disturbed.

A piece of land, about 50 sq. yards in area, containing hundreds of young grubs was dug up but not a single grub was exposed to the surface. One hundred grubs, which were liberated in a space of two square yards of dug-up area, entered the ground in one hour and 20 minutes, but when liberated on hard, undug, practically dry land, they could not enter the ground and were taken away by ants. Digging and hoeing disturb their positions in the soil, but they still remain covered with moist soil in most cases which is the only requirement to keep them alive. Very few are actually injured or killed with the implements at the time of digging. These observations show that digging is ineffective for destroying the young grubs present in the ground.

MOVEMENTS OF THE GRUB IN THE SOIL

(*a*) Four glass cages with moist soil and bits of roots buried in it were kept in the laboratory and two grubs were liberated in each of them. It was observed that the grubs moved about at random inside the soil, sometimes going downwards and returning upwards or going towards the sides of the cages. Very often they were seen making rounds in the same direction over and over again. For several days they went on moving about in the soil without coming in contact with the food material which was placed very close to them. Sometimes they happened to reach within a quarter of an inch of the food material yet they did not seem to realize it and came back. Out of eight grubs only one found the roots within 30 hours, three between 9 and 13 days, and the rest died without being able to reach the roots.

(*b*) One hundred young grubs were liberated in a cage at a distance of three feet from the roots buried in the same cage. On examination of the roots after four months, only seven grubs were found to have attacked the roots, showing that only a small percentage can reach the roots if they hatch about three feet away from them.

(*c*) Out of 220 grubs liberated on the roots of four apple trees only three could attack the roots.

These observations indicate that the newly hatched grub has no food direction sense.

Observations on the movements of grown-up borers also lead to the same conclusion. The movements of four grubs were traced for eight months. None moved in any particular direction and the average monthly movement was about four inches in a month. The movements of three grubs, liberated in the ground near an apple tree at one foot, three feet and five feet away from it, were traced for two months. Only one of them, which was liberated one foot away from the base of the tree, succeeded in reaching the roots. The movements of any of them were not necessarily towards the roots. These observations also showed that after leaving a root, the borer often remains at the same place for over a month. It does not move in any particular direction and often returns to the same spot from where it had started. It moves about at random and in a very zigzag way, mostly remaining within a few inches of its starting place.

NATURE AND MODE OF INJURY

Examination of the borer-attacked roots of 155 apple trees at Chaubattia in 1935 has shown that it feeds only on thick portions of roots. The rootlets and the ends of main roots remain in the ground, dislocated. The minimum thickness of a root on which a borer was observed feeding was 0·83 in. in diameter. In most cases the attacked root is cut off from the base. Out of 155 roots attacked, 144 were completely severed from the bases of the trees. In 52 out of 155 cases the root was found severed from the base but there was no borer feeding on it. It had either disappeared or had started feeding on another root close to it. In other cases the borer attacked a root near the base of a tree and followed it on towards its tip. The root was either bored or girdled if it was not thick enough to hold the borer. In 94 per cent cases, the root was attacked just at the base of the tree. In other cases, the borer generally started feeding from within a distance of four inches from the base. The depth at which the attack started varied from 2 and 11 inches but in 95 per cent cases borer started feeding between 4 and 8 inches depth.

ALTERNATIVE FOOD MATERIAL OF THE BORER

In nature large borer grubs identified as *Lophosternus hugelii* Red. have been found feeding mostly on the roots of apple and dead stumps of oak. Very rarely roots of walnut, pear, peach and cherry have shown signs of damage by this borer. Pieces of root of all the fruit trees grown in Chaubattia orchard and of oak, rhododendron and pine were buried in moist soils in separate cages in August 1935 and 60 young grubs were liberated in each cage in the same month. Roots of all the cages were examined in December of the same year. Percentage survival of grubs in different cages was : apple 38, walnut 32, pear 15, peach 50, plum 17, cherry 20, apricot 45, nectarine 23, oak 18, pine 25, and rhododendron 23.

Observations were also made on the food material of grown-up borer. Roots of apple, pear, peach, plum, apricot, chestnut and walnut were buried separately in soil and five grown-up borers were liberated on each on June 6, 1936. A similar set of cages was arranged two months later and borers were similarly liberated. During the first few months they fed on all the roots and a few lived in every cage till September 1938. After that all the grubs died in cages containing cherry roots, but lived on all other roots till January 1937. Between January and June of the same year, all borers died on pear roots and a few months later on apricot roots also. In August 1938, living borers were found only on apple and chestnut roots. After this all the borers except one on chestnut roots gradually died. This one had made a pupating chamber in February 1939, but died while still in pupal stage. These observations show that the borer is likely to feed on roots of all the fruit trees grown in Kumaun hills when forced to do so.

SUMMARY AND CONCLUSIONS

Lophosternus hugelii Red. is a very serious pest of apple trees in Almora and Naini Tal districts, where in certain portions of every orchard about 40 per cent of the trees are attacked. Very few of the attacked trees survive and bear normal crop. It is recorded from all the hills in northern India up to a height of about 7,000 feet and also from Siwaliks. It attacks both living and dead apple roots and is found mostly on underground portions of dead oak stumps. Fruit trees other than apple rarely show signs of damage by this borer.

All the stages of the insect have been described.

Beetles emerge from the ground just after the break of monsoon and mating and egg-laying take place soon after emergence. Eggs are laid in the ground to a depth of about 8 mm. and most of the eggs hatch in 24-29 days. One female lays on an average about 300 eggs. After hatching the young grubs move about in the ground at random as they do not possess any food direction sense. They attack apple roots if by chance they come across them. They go on feeding on roots of apple and dead stumps of oak for about 3½ years, after which they leave them, make small chambers of earth and retire in them to pupate. Normally the adult stage is reached by the middle of June and beetles emerge after the first heavy shower in the end of June or beginning of July.

The results of the experiments carried out to see the effect of different soils and moisture contents upon oviposition response, development of egg and survival of young grubs have definitely indicated that 20—40 per cent saturation of soil is most suitable for egg laying and development of egg in all the three kinds of soils, viz. clayey, sandy and organic, and that sandy soil is preferred by the beetle for depositing eggs. In all soils mortality of the grubs is accelerated by the increase of moisture above 40 per cent saturation. In nature large borer grubs have been found feeding mostly on roots of apple and dead stumps of oak. Roots of walnut, pear, peach and cherry have very rarely shown signs of damage by this borer but in confinement it feeds on roots of all the fruit trees grown in Kumaun hills. Temporary shortage of soil moisture below 20 per cent saturation on or about 12th day after laying is fatal to eggs but does not seem to affect much the younger and older ones. In dry soils young grubs cannot live for more than seven hours but in moist soil with only a trace of organic matter in it, they survive for about a month. If the upper few inches of ground containing young grubs gets dry, some of the young grubs by chance reach the moist soil below but quite a few come to the surface in dry soil and die. Digging or hoeing of the ground does not effect any substantial reduction in the number of eggs and newly hatched grubs as the egg-shell is hard enough to withstand the ordinary sifting of soil and young grubs re-enter the soil if exposed to the surface. In captivity borer feeds on roots of all kinds of fruit trees grown in Kumaun hills and of oak, pine ad rhododendron. The first attack of the borer on apple root starts near the base of the tree at a depth of about 4—8 in. It attacks the thick roots only, rootlets and ends of the main roots remain in the ground, dislocated from main roots. After leaving a root borer moves about very slowly, generally, at the rate of about 4 in. in a month, and not necessarily in the direction of another root. Grown-up borer can survive in soil without any root for about three months. If during this period it comes in contact with some root, it attacks it, otherwise it dies inside the ground. The chances of a borer attacking another root after leaving one are, therefore, very rare.

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REFERENCES

Beeson, C. F. C. (1919, 1). *Indian For. Rec.* **7,** 19
——————— (1919, 2). *Indian For.* **45,** 146
Fletcher, T. B. (1917). *Proc. Ent. Mtg. Pusa* **2,** 248
Gahan, C. J. (1906). *F. B. I. Coleoptera* **1,** 11
Gardner, J. C. M. (1927). *Indian For. Rec.* **13,** 33
Redtembach, L. (1848). *Hugel's Kaschmir* **4,** 550
Stebbing, E. P. (1914). *Indian forest insects,* pp. 274-5 : Eyre and Spottiswood, Ltd., London

APPENDIX

Effect of temporary shortage of soil moisture upon newly hatched grubs

Cage No.	Description of cages	No. of grubs liberated	Where liberated	Observations		
				One hour later	Two hours later	24 hours later
I	2 in. moist soil above 2 in. dry soil below	20	In dry soil	8 seen moving about at random in dry soil	One has gone to moist soil	10 found in moist soil, 4 in dry soil which had become partially moist by that time and 6 were found dead in dry soil
II	2 in. dry soil above 2 in. moist soil below	20	In moist soil	4 moving in dry soil and the rest in moist soil	None visible, traces of their movements in both dry and moist soils	Grubs had gone up to 1½ in. in dry soil. 6 were found in dry soil which had absorbed moisture by that time, 12 in moist soil and 2 found dead in dry soil
I (*a*)	2 in. moist soil above 2 in. dry soil below	20	In moist soil	None has gone to dry soil	There are traces of their movements in dry soil	10 found in moist soil and 10 in dry (partially moist) soil. All living
II (*b*)	2 in. dry soil above 2 in. moist soil below	20	In dry soil	4 have come out on the surface and 8 have gone down in moist soil	3 on the surface, 1 entered the soil, rest not visible	10 in moist soil, 8 in dry (partially moist) soil and 2 found dead on surface

STUDIES ON KUMAUN HILL SOILS

II. EFFECT OF TERRACING AND CULTIVATION ON SOIL TYPES AT CHAUBATTIA*

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THE soil formations under unterraced, i.e. natural conditions, together with the geology, vegetation and climate of Chaubattia have already been reported [Mukerji and Das, 1940]. The climate of this station approximates to that of humid temperate zones. The parent rock materials are mostly biotite-schists and granite-gneiss. At some places both granite and biotite appear to be present intimately mixed with each other. The common vegetation all over these hills is typical of the forest flora generally found in the humid temperate zones. As already indicated [Mukerji and Das, 1940] four major genetic types of soil formation occur on this orchard. These are brown forest soils, podsols, red loams, and wiesenboden, of which brown forest soils, constituting the greater part of the orchard is by far the most important for fruits like apples, pears, peaches, plums, apricots, etc.

One of the most important pedogenic features observed previously is that there is under natural conditions a marked tendency for the brown forest soils to assume certain characteristics of podsol formations. The present paper has been written with the main object of showing how the usual practice of land utilization in these hills by terracing and cultivation on terraces affects the natural dynamical processes of soil formations in this locality. In view of the importance of brown forest soils to fruit growing in these hills, attention has in the present instance been wholly directed to the pedological changes in relation to this genetic type and its variants.

The Chaubattia orchard has a northern aspect, which is the best for growing temperate fruits, with an elevation of 6,100 to 6,900 feet above sea-level. The total area of the orchard is 158·61 acres of which about 100 acres are laid out with blocks of all temperate fruits and the remaining portion is under forest. Out of the 100 acres under fruits, an area of about 85 acres is terraced and the remaining only 15 acres is under contour plantation. A

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detailed study of the effect of terracing on the natural soil types of this station constitutes, therefore, a very important item in the programme of the soil work in progress.

Apart from all other considerations, the successful function of terracing lies in the fact that it results in checking soil erosion along slopes on one hand, and conserving subsoil moisture on the other. The usual bench type of terraces which are suitable for the hill conditions does check erosion to a considerable extent ; but for moisture conservation these do not appear to be effective, particularly along very steep gradients. Along steep slopes the subsoil remains immature and sandy. The detailed soil survey of the orchard shows that subsoil texture and therefore moisture conservation in the subsoil regions are dependent on the slope conditions. It will be clear from Table I in which the distribution of 716 profiles according to slope gradients has been shown that sandy profiles are mostly situated along slope gradients of 45° and more.

TABLE I

Textural characters of soil profiles along different slope gradients

Serial No.	Textural characters of profiles	Total number	Distribution of profiles according to slope gradients in degrees						
			10°	20°	30°	45°	50°	60°	More than 60°
1	Stony and sandy . .	378	1	5	8	68	89	143	64
2	Loamy	153	2	6	12	51	41	37	4
3	Clayey	185	9	18	52	77	21	7	1

LITERATURE

The scientific study of soils particularly in Europe and America has now definitely established the nature and properties of the various genetic types. The possibilities of this method of soil classification from the point of view of land utilization for agricultural purposes are being thoroughly investigated by the soil scientists all over the world. Reference in this connection may be made to the works of Norton [1939], Kellog [1937] and de Sigmond [1932]. The clear recognition of the dynamic reactions of the soil types to the different cultural operations necessary for agronomic utilization has opened up a very profitable field of research in which much fundamental work yet remains to be done.

Brown forest soils or the so-called brown earths have not been assigned a definite place in the International classification of soils. Some have considered brown forest soils to be a definite soil type ; whereas, others would like to call these ‘ concealed podsols ’ in which the podsolic processes in progress have not fully expressed themselves. This confusion is due mainly to the fact that sufficient account has not been taken in every case of the environments of the brown forest soil studied.

It appears from the investigation of Muller [1887] on Danish heaths that brown earths due to a change in vegetation factor can slowly change into podsols. Tamm [1932], however, clearly postulates the view that 'there is no general tendency, as some believe, towards the podsolization of brown forest soils. The reverse is much in evidence' and that 'the brown forest soils as a climatic type are very apt to persist; they belong to the medium humid temperate climate where deciduous forests represent the natural vegetation'. Balleneggar [Joffe, 1936] has found the soil from ploughed field to be more podsolized than one from beach forest. In dealing with the incipient podsolic processes in brown earths, Jack [1934, 1] says: 'The process is one of simple solution by carbonated rain water, and goes on continuously in the humid brown earth climate. There should therefore be a tendency towards increasing soil acidity, and if this happens, the vegetation may ultimately change from deciduous to coniferous forest and podsolization will occur. But if the vegetation can absorb sufficient bases and return them in the humus sufficiently quickly for the soil to counteract the leaching effect, the brown earth and its corresponding vegetation form a stable system which is only disturbed by the slow wastage that accompanies every natural process'. The following has also been taken from the work of the above author [Jack, 1934, 2]: 'An interesting phenomenon sometimes arises when birch replaces beech or coniferous forest on podsolized soils. Birch produces a slightly acid well buffered type of humus, and in course of time may reverse the podsol process that went on under the earlier vegetation; the soil gradually develops the characteristics of a brown earth—a more fertile soil type than the podsol. This represents a kind of natural regeneration of the soil, and birch now holds a high place as a soil improver in the silviculture of many northern countries'. A review of all the available informations leads one to the conclusion that podsolic formation is a reversible process and this seems to have been confirmed by the studies reported in the present paper.

A number of terraced and cultivated soils has been studied by Shaw [1932] in Eastern Central China. It appears from his descriptions that these soils possess certain brown earth characteristics.

METHODS AND PROCEDURE

FIELD SURVEY

A detailed survey of the terraced soils of the Chaubattia orchard at 50 feet, both along and across the slopes, has been completed. The unit of our study was taken to be the soil profile. Pits were dug at the corresponding points of horizontal and vertical cross-lattices of the orchard map at regular distances of 50 feet apart. These pits were sufficiently broad for an observer to go inside and note visually the profile characteristics. In soils other than the clayey ones, digging of pits for soil survey was continued up to the partly decomposed parent material. In the case of clayey profiles, however, the pits were dug up to the impervious clay pan.

Observations in regard to the characteristics of each horizon, particularly colour, texture, structure, depth, hardness, concretions and cementations were made *in situ* and representative samples were obtained from each horizon for laboratory studies. Due chiefly to their positions along different slopes and aspects the soils under field conditions were found to have different moisture contents and, therefore, it was felt desirable to supplement field observations on colour and texture with similar observations made in the laboratory under fairly uniform and controlled conditions. The soil samples obtained from the fields were therefore air-dried, and observations on colour and texture repeated under air-dried and moisture-saturated conditions. This undoubtedly afforded a fuller knowledge of the horizons than that based on observations noted in the field alone.

ANALYTICAL METHOD

Air-dry sample was broken down with a wooden pestle and passed through 2 mm. sieve ; the materials remaining on the sieve were reported as stones and gravels. Two-millimetre samples were used for both mechanical and chemical analysis.

Mechanical analysis

Pretreatment and dispersion were effected according to the recommendations of the International Society of Soil Science, followed by pipette sampling for silt and clay.

Chemical analysis

Hydrochloric acid extract was prepared according to the directions of the British Agricultural Education Association [Wright, 1939]. Lime and magnesia were both determined titrometrically. Sesquioxides were precipitated by ammonium chloride and ammonia, and iron estimated by titration with standard potassium permanganate.

Organic carbon.—This was estimated by Walkley and Black's [1934] method with potassium dichromate and ferrous sulphate.

Organic nitrogen.—For the determination of total organic and ammoniacal nitrogen, the usual Kjeldahl's method was followed after pre-treating the soils as suggested by Bal [1925].

p*H*.—The quinhydrone electrode method was adopted for the determination of *p*H values with soil and double distilled conductivity water : ratio 1: 2·5.

Exchangeable acidity and base exchange capacity. -- These two were determined in the same sample by Parker's barium acetate and ammonium chloride method [Pierre and Scarseth, 1931], and percentage base saturation was calculated according to the formula given below :—

$$\text{Per cent base saturation} = 100 - \frac{\text{Exchangeable hydrogen} \times 100}{\text{Base-exchange capacity}}$$

Clay analysis.—Clay samples were collected according to the method suggested by Robinson [1932] and were analysed as a silicate after fusion with sodium carbonate.

Moisture.—10 gm. of air-dry soil were dried in an oven at 105°C till constant weight. The loss in weight was reported as hygroscopic moisture.

Loss on ignition.—The oven-dry soil was ignited with frequent stirring at slow red heat till constant. This operation takes usually six hours.

DATA AND DISCUSSION

In all 30 complete profiles from terraced areas scattered over the orchard have been analysed. The analytical data in regard to five typical profiles are given in Tables II—XI. The visual survey of 716 profiles from all the terraced part of the orchard has shown that the soils which have in course of time consolidated possess certain characteristic features necessitating their classification under two main groups. Soil profiles examined on the terraces, prepared only recently, have not been included in our present studies, as the natural soil forming features have had no time yet to stabilize themselves on these soils.

BROWN FOREST SOILS

A large majority of the terraced soils so far studied by us can be classified as brown forest soils. The descriptions of three typical profiles, one from each of sandy, loamy and clayey textural groups, are given below :—

Name of the Profile	Texture of the Profile	Depths	Horizons	Descriptions
13 R 4 .	Sandy .	0—4 in. .	A	Micaceous ; brownish grey ; sandy ; structureless and stony ; more grey when wet.
		4 in.—3 ft.	B	Brownish ; more brown when wet ; stony sandy ; more sandy than above but more compact. Structure not pronounced cloddy.
		3—5 ft.	C	Yellowish ; micaceous ; more yellow when wet ; sandy ; stony with no structure ; consistancy loose.
X18 Y 7 .	Loamy .	0—6 in. .	A	Greyish brown ; micaceous ; loamy with some stones ; more grey when wet ; angular cloddy with medium particles to big granules.
		6 in—1 ft. 6 in.	B	Brown ; more brown when wet ; silty loam ; more indurated than above ; medium to big clods.
		1 ft. 6 in.—2 ft. 10 in.	C	Micaceous ; yellowish brown ; structureless ; brownish when wet ; sandy with very many stones.
15 R 3 .	Clayey .	0—5 in. .	A	Greyish brown ; stony loam ; more grey when wet. Finely granular to crumby with plenty of feeder roots.
		5 in.—1 ft. 6 in.	A2	Yellowish brown ; more brown when wet. Medium to fine clods ; clayey.
		1 ft. 6 in.—2 ft. 8 in.	B	Brown ; more brown when wet. Big clods resembling more or less columns. Very clayey.
		2 ft. 8 in.—3 ft. 6 in.	B+C	Brownish ; intense brown on wetting. Clayey with very many air holes ; prismatic with dark circular incrustations, and concretions.

The analytical data of the above profiles—chemical and mechanical—are given in Tables II—VII.

TABLE II

Analytical results of terraced brown earths—sandy soils

Chemical

Name of profile	Depth	Horizon	Determinations.										
			Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	pH	Insoluble matter in strong HCl (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	MgO (per cent)	CaO (per cent)
13 R 4	0—4 in.	A	1·67	4·93	1·17	0·077	15·2	6·4	80·39	4·80	9·19	0·48	0·159
"	4 in.—3 ft.	B	1·20	3·04	0·33	0·034	9·6	6·6	83·68	4·80	7·20	0·39	0·084
"	3—5 ft.	C	1·22	3·11	0·11	0·036	3·1	6·8	83·20	5·04	6·31	0·24	0·007

TABLE III

Analytical results of terraced brown earths—sandy soils

Mechanical

Name of profile	Depth	Horizon	Determinations						
			Stones and gravels (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay(per cent)	Exchange H.m.e. (per cent)	Per cent base saturation
13 R 4 . .	0—4 in. . .	A	15·9	34·00	33·06	14·55	17·65	0·088	98·53
	4 in.—3 ft. .	B	34·8	40·17	36·53	7·65	12·00	0·088	98·27
	3—5 ft. . .	C	37·9	43·30	43·40	7·500	5·40	0·875	72·66

TABLE IV

Analytical results of terraced brown earths—loamy soils

Chemical

Name of Profile	Depth	Horizon	Determinations											
			Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	pH	Insoluble matter in strong HCl (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	R_2O_3 (per cent)	MgO (per cent)	CaO (per cent)
X18 Y7	0—6 in.	A	1·9	3·70	0·70	0·07	10·03	5·8	79·8	5·40	8·20	13·6	0·10	0·049
	6 in.—1 ft. 6 in.	B	2·5	3·44	0·31	0·06	5·16	5·3	77·1	6·20	10·00	16·2	0·07	0·028
	1 ft.6 in.—2 ft. 10 in.	C	1·3	2·23	0·39	0·05	7·80	5·5	82·4	5·68	6·82	12·5	0·15	0·035

TABLE V

Analytical results of terraced brown earths—loamy soils

(Mechanical analysis of 2 mm. sample)

Name of profile	Depths	Horizon	Determinations						
			Stones and gravels (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Exchange H. m. e. (per cent)	Per cent base saturation
X18 Y 7 . .	0—6 in. . .	A	10·8	12·71	49·67	20·75	16·25	*Nil.*	100
	6 in.—1 ft. 6 in. .	B	5·6	10·56	27·60	29·40	23·10	0·613	94·38
	1 ft. 6 in.—2 ft. 10 in.	C	29·9	46·82	39·84	4·60	8·70	0·700	87·72

TABLE VI

Analytical results of terraced brown earths—clayey soils

(Chemical)

Name of profile	Depth	Horizon	Determinations											
			Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	C/N	pH	Insoluble matter in strong HCl (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	MgO (per cent)	CaO (per cent)	R_2O_3 (per cent)	Organic nitrogen (per cent)
15 R 3	0—5 in.	A_1	3·05	5·83	1·79	15·2	6·3	75·80	5·60	7·82	0·33	0·131	13·42	0·118
	5in.—1 ft. 6 in.	A_2	3·06	4·20	0·62	9·9	5·6	76·74	6·08	7·74	1·32	0·131	13·82	0·063
	1 ft. 6 in.—2 ft. 8 in.	B	3·34	3·64	0·22	5·6	5·3	77·64	6·24	7·51	1·08	0·084	13·75	0·039
	2 ft. 8 in.—3 ft. 6 in.	B+C	3·63	4·11	0·30	6·4	5·1	76·63	5·92	7·71	0·72	0·112	13·63	0·046

TABLE VII

Analytical results of terraced brown earths—clayey soils

(Mechanical analysis of 2 mm. sample)

Name of profile	Depth	Horizon	Determinations						
			Stones and gravels (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Exchange H. m.e. (per cent)	Per cent base saturation
15 R 3 . .	0—5 in. . .	A_1	3·0	6·76	29·65	33·00	29·80	0·612	95·02
	5 in.—1 ft. 6 in. .	A_2	...	0·20	27·23	43·25	29·75	4·46	60·18
	1 ft. 6 in.—2 ft. 8 in.	B	...	0·39	27·19	41·45	31·45	8·05	48·06
	2 ft. 8 in.—3 ft. 6 in.	B+C	...	0·44	24·17	39·50	35·25	8·05	64·85

It is evident both from visual observations and analytical data given above that these profiles are typical of brown forest soils, notwithstanding the fact that considerable disturbances have been brought about by cultivation and terracing operations.

TRANSITIONAL PODSOLS

The authors have already given a complete account of visual profile characteristics and relevant analytical data for some of the typical podsol formations at Chaubattia under unterraced natural conditions. A large number of profiles showing podsolic tendencies have now been studied in the terraced portions of the orchard. The visual characters of two such typical profiles are recorded below :—

Profile	Depth	Horizon	Description
X15 Y15	0—8 in. . .	A_1	Grey ; granular ; loamy ; dark grey when wet.
	8 in.—2 ft. 8 in. .	. .	Same as above in air-dried condition but slightly darker *in situ*.
	2 ft. 8 in.—3 ft. 5 in.	A_2	Silty loam ; laminated ; structureless ; yellowish ; brownish yellow when wet.
	3 ft. 5 in. and below	B	Hard ; brownish yellow, clayey soil ; deep brown when wet. Whitish incrustations round prismatic soil mass. Hard pan below.
X12 Y21	0—1 ft. 2 in. .	A_1	Organic ; silty clay ; when wet brownish grey ; granular.
	1 ft. 2 in.—2 ft. 2 in.	A_2	Organic loam ; brown ; coarsely granular ; when wet reddish brown.
	2 ft. 2 in.—3 ft. 1 in.	A_3	Organic clayey with mica rock pieces ; platy yellowish brown ; when wet dark brown.
	3 ft. 1 in.—3 ft. 7 in.	B	Clayey ; whitish incrusations ; brown ; when wet deep brown ; hard ; prismatic ; micaceous.
	3 ft. 7 in.—4 ft. 8 in.	B+C	Yellowish brown ; when wet brown ; micaceous sandy ; indurated with infiltered clay.

The whitish cementations in the B horizon of both these profiles round prismatic soil mass and the platy or laminated nature of a part of the A horizon indicate as far as visual observations go the podsolic nature of both the profiles. Chemical and mechanical analyses of both the profiles are given in Tables VIII and IX.

TABLE VIII

Analytical results of terraced podsolic soils

(Chemical determinations)

Name of profile	Depth	Horizon	Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	pH	Insoluble matter in strong HCl (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	R_2O_3 (per cent)	$\frac{SiO_2}{R_2O_3}$	MgO (per cent)	CaO (per cent)
X15 Y15	0—8 in.		3·45	7·19	2·22	0·21	10·56	6·3	71·01	5·09	10·45	15·54	4·57	1·25	0·358
	8 in.—2 ft. 8 in.	A_1	4·18	8·49	3·00	0·19	15·77	6·1	69·14	5·23	10·97	16·20	4·26	1·44	0·329
	2 ft. 8 in.—3 ft. 5 in.	A_2	2·65	2·97	0·27	0·06	4·31	5·6	77·58	4·61	9·86	14·47	5·36	1·07	0·105
	3 ft. 5 in. and below.	B+C	3·02	2·56	0·34	0·06	5·21	5·6	76·95	3·86	10·13	13·99	5·50	1·58	0·238
X12 Y21	0—1 ft. 2 in.	A_0	2·94	7·13	2·11	0·18	11·7	6·7	73·74	5·09	9·29	14·38	5·13	0·90	0·308
	1 ft. 2 in.—2 ft. 2 in.	A_1	3·05	3·53	1·74	0·07	24·9	6·2	76·76	5·83	8·16	13·99	5·49	1·52	0·175
	2 ft. 2 in.—3 ft. 1 in.	A_2	2·68	3·50	0·67	0·05	13·4	5·5	77·70	4·95	9·53	14·48	5·37	1·18	0·098
	3 ft. 1 in.—3 ft. 7 in.	B	3·13	3·00	0·65	0·05	13·0	5·4	77·70	4·99	9·02	14·01	5·90	1·07	0·063
	3 ft. 7 in.—4 ft. 8 in.	B+C	1·12	2·73	0·77	0·03	25·7	6·0	82·87	4·85	7·04	11·89	6·97	0·58	0·035

TABLE IX

Analytical results of terraced podsolic soils

(Mechanical determinations)

Name of profile	Depth	Stones and gravels (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Exchange H. m. e. (per cent)
X15 Y15 .	0—8 in. . .	0·3	1·60	28·31	47·20	26·50	0·26
	8 in.—2 ft. 8 in. .	0·2	0·53	20·82	42·65	28·95	0·96
	2 ft. 8 in.—3 ft. 5 in.	...	0·95	24·97	43·10	24·10	5·78
	3 ft. 5 in. and below	...	0·32	23·02	44·35	26·15	3·32
X12 Y21 .	0—1 ft. 2 in. .	4·4	6·78	33·03	32·05	24·20	0·044
	1 ft. 2 in.—2 ft. 2 in.	...	1·24	32·54	38·20	25·90	0·131
	2 ft. 2 in.—3 ft. 1 in.	8·1	4·32	35·82	37·10	21·60	0·175
	3 ft. 1 in.—3 ft. 7 in.	10·7	4·85	32·53	36·80	24·85	1·312
	3 ft. 7 in.—4 ft. 8 in.	5·0	16·17	45·73	15·30	20·15	1·750

It is evident from Tables VIII and IX that in spite of morphological characteristics pointing to the similarity of these soils with transitional podsols there is hardly any general indication of colloidal matter, clay, organic carbon and lime having been eluviated from A horizon. Similarly iron and alumina do not tend to have undergone any eluviation whatsoever. The trend of changes in regard to *p*H and exchange acidity also shows that these profiles have fundamental characteristics of brown forest soils. With a view to be able to elucidate further the nature of these profile formations, it was considered necessary to analyse the clay fractions of these soils. The results of clay fraction analysis are given in Table X.

TABLE X

Analysis of clay fraction—terraced podsolic soils

Profile	Depth	Horizon	SiO_2 (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
X15 Y15 .	0—8 in. . .	...	47·20	14·37	28·63	2·734	2·116	3·119
	8 in.—2 ft. 8 in. .	A_1	47·62	14·37	26·03	3·101	2·292	2·836
	2 ft. 8 in.—3 ft. 5 in.	A_2	50·88	13·17	22·43	3·845	2·796	2·666
	3 ft. 5 in. and below.	B+C	51·72	13·17	21·43	4·091	2·937	2·547
X12 Y21 .	0—1 ft. 2 in. .	A_0	45·90	15·17	19·63	3·962	2·658	2·026
	1 ft. 2 in.—2 ft. 2 in.	A_1	47·78	13·57	21·73	3·726	2·664	2·507
	2 ft. 2 in.—3 ft. 1 in.	A_2	49·58	13·97	19·33	4·346	2·974	2·166
	3 ft. 1 in.—3 ft. 7 in.	B	52·50	12·78	19·32	4·606	3·237	2·367
	3 ft. 7 in.—4 ft. 8 in.	B+C	48·32	15·97	19·13	4·281	2·792	1·875

Although there is an indication of accumulation of Fe_20_3 in the lower horizons of profile X12 Y21 it is clear from the table above that there is no general tendency of eluviation of the sesquioxides in the profiles. On the other hand the constancy of $\frac{SiO_2}{R_2O_3}$, $\frac{SiO_2}{Al_2O_3}$ and $\frac{Al_2O_3}{Fe_2O_3}$ ratios throughout the solum shows that profiles such as these are typical brown forest soils [Robinson, 1930; Mukerji and Das, 1940]. The high ratio of $\frac{SiO_2}{R_2O_3}$ establishes clearly the fact that weathering in these profiles is primary. Thus it is quite evident that profile X15 Y15 is a typical brown forest soil and profile X12 Y21 has podsolic tendency.

The reasons for these podsolic profiles showing some brown forest soil characters will be clear from a consideration of the percentage base saturation figures of the profiles given in Table XI. It will be noticed that in spite of high base saturation of the surface layers the lower layers are still showing considerable degree of unsaturation, specially in the case of profile X15 Y15. This indicates that the process of transformation of the podsols into brown forest soils due to terracing is in some cases not quite complete.

On a joint consideration of the data given in Tables X and XI, and particularly because of the presence of silicious material round structural soil mass of B horizons, these soils have been classified as transitional podsols, where it appears that the dynamics of the podsolic soil formations have undergone a reversal to brown forest soil type under terraced conditions. Although on the average the base exchange capacity of these soils is rather low, the high percentages of base saturation of the surface soils may be responsible for bringing about a reversal of these podsolic soils.

TABLE XI

Percent base saturation—terraced podsolic soils

Profile	Depth	Horizon	pH	Exchange acidity (m. e. per cent)	Base-exchange capacity (m. e. per cent)	Base-saturation (per cent)
X15 Y15	0—8 in.	...	4·2	0·26	15·2	98·29
	8 in.—2 ft. 8 in.	A_1	4·0	0·96	16·9	94·32
	2 ft. 8 in.—3 ft. 5 in.	A_2	3·6	5·78	13·7	67·81
	3 ft. 5 in. and below.	B + C	3·6	3·32	22·2	85·05
X12 Y21	0—1 ft. 2 in.	A_0	4·7	0·044	14·3	99·69
	1 ft. 2 in.—2 ft. 2 in.	A_1	4·1	0·131	12·5	98·95
	2 ft. 2 in.—3 ft. 1 in.	A_2	3·9	0·175	11·6	98·49
	3 ft. 1 in.—3 ft. 7 in.	B	3·8	1·312	21·6	93·93
	3 ft. 7 in.—4 ft. 8 in.	B + C	3·9	1·75	8·7	79·89

GENERAL DISCUSSION

In the foregoing pages the results of a critical study of soil types found under terraced and cultivated conditions at Chaubattia have been given. In spite of the disturbances caused to the soil profiles by terracing and cultivation it is interesting to note that the essential features of brown forest soils have persisted. Podsolic formations, on the other hand, seem to have undergone changes, and show certain characteristic features of brown forest soils. A highly base-sturated A-horizon is one of the peculiar characteristics of these profiles. This high base-saturation can be attributed above all to the following two reasons :—

(*i*) Due mainly to the manuring practices, considerable amount of organic matter and bases are added to the surface soils ; and

(*ii*) leaf fall of fruit trees adds considerable amount of bases and humus to the surface soil, and these at the time of annual digging of the terraces are thoroughly incorporated into the soil.

From the data presented in this paper it is clear that brown forest soil is the only soil type which is in equilibrium with the diverse factors underlying the raising of temperate fruits by terracing and cultivation. Had it not been so some of the characteristics in the dynamics of brown forest soil formation should have been modified to suit the altered conditions.

Podsolic formations being unstable under the conditions peculiar to the growing of fruit trees in these hills, have assumed brown forest soil features which are much more suitable for fruit growth under the conditions generally prevailing in the Kumaun hills.

The pedogenic processes giving rise to the formation of brown forest soils are somewhat similar to those causing the development of podsols, and the latter appear to be the end product of a series of natural operations that bring about the formation of brown forest soils at an intermediate stage. The brown forest soil characteristics of the terraced podsolic soils studied by us can only be ascribed to a reversal of this process taking place under terraced and cultivated conditions. This hypothesis clearly explains why under terraced and cultivated conditions a fully developed podsolic formation is rarely met with. The dynamics of the soil formation under this multiphase system of fruit growing can be represented graphically as follows :—

Contour planting←————————Brown forest soils
↑
and   Fruit growing, terracing and cultivation
↑
erosion————————————→Podsols

Terracing as an agronomic practice is followed all over the world for the profitable utilization of soils which are liable to severe erosion. Different types of terraces have, therefore, been found suitable under different topographical and climatic conditions. Terracing and cultivation on terraces along the hill slopes as practised in Kumaun have their peculiar problems, particularly where these hill soils are utilized for the development of fruit cultivation.

The detailed examination of 716 profiles under different gradients shows that topographically immature sandy and stony soils are found mostly along slope gradients of 45° or more. The subsoils of all such immature profiles remain light, loose, and unconsolidated under terraced conditions with the result that the finer soil material of the subsoil gets washed away during monsoon and the water retaintivity of the profile as a whole becomes on that account very low. Due to this and other incidental factors the growth of apple and other fruit trees in such localities of immature soil formation is very poor, and in dry periods signs of leaf drooping and set back in growth are very common. It will thus appear that utilization of such topographically immature soils is not likely to yield the desired effect.

SUMMARY

1. Terraced soils studied at the Government Orchard, Chaubattia in the Kumaun hills show that the textural characters of profiles depend on the slope gradients. Sandy soils are found mostly along gradients of 45° or more; whereas, loamy and clayey soils are usually met with under milder slope conditions.

2. The genetic soil type met with under terraced conditions are mostly brown forest soils, textural characters of the profiles of which depend on slope gradients.

3. Terracing and cultivation as practised for fruit growing tend to make podsolic soil types assume certain characteristics of brown forest soils.

REFERENCES

Bal, D. V. (1925). *J. agric. Sci.* **15**, 454
de Sigmond, A. A. J. (1932). *Imp. Bur. of Soil Sci. Tech. Com. No.* **23**
Jack, G. V. (1934). *Imp. Bur. of Soil Sci. Tech. Com. No.* **29**
Joffe, J. S. (1936). *Pedology*, p. 321 : Rutgers Univ. Press, N. J.
Kellog, C. E. (1937). *U. S. Dept. Agric. Misc. Pub. No.* **274**
Mukerji, B. K. and Das, N. K. (1940). *Indian J. agric. Sci.* **10**, 990
Muller, P. E. (1887). *Studies uber naturlichen Humus Formen* : Berlin
Norton, E. A. (1939). *U. S. Dept. Agric. Misc. Pub. No.* **352**
Pierre, W. H. and Scarseth, G. D. (1931). *Soil Sci.* **31**, 99
Robinson, G. W. (1930). *J. agric. Sci.* **20**, 618
——————— (1932). *Soils, their constitution and classification*, p. 214 : Thomas Murby & Co., London
Shaw, C. F. (1932). *2nd Internat. Cong. Soil Sci.* **5**, 399
Tamm, O. (1932). *2nd Internat. Cong. Soil Sci.* **5**, 178
Walkley, A. and Black, I. A. (1934). *Soil Sci.* **37**, 29
Wright, C. H. (1939). *Soil analysis* (2nd edition), p. 206 : Thomas Murby & Co., London

FRACTIONATION OF PHOSPHORIC ACID IN ORGANIC MANURES*

BY

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It has been found by various workers that a considerable portion of the total phosphorus of grassland and fen soils is in organic form. The organic phosphorus of arable soils is comparatively small and is mainly derived from the crop residues and from organic manures used as fertilizers. The fate of the organic phosphorus upon entering the soil and the form into which it is ultimately converted are yet uncertain and controversial [Ghani, 1938].

It is, therefore, interesting to know the proportion of organic and inorganic phosphorus in such manures and the form in which they are present in them. Such an analysis may give useful information about the fertilizing value of the organic manures.

Funatsu [1908] determined the phosphoric acid in the form of lecithin and nuclein and in a form soluble in dilute hydrochloric acid in several manure cakes and found that the amounts of lecithin and nuclein were comparatively small. Tsuda [1909] made a quantitative determination of different forms of phosphoric acid in several organic manures of vegetable and animal origin. He found that the animal manures had their phosphorus mainly in the inorganic form and the vegetable ones mainly in the organic form.

Experimental

Samples of poultry manure (both fresh and kiln dried), farmyard manure and Adco compost were analysed by a method of fractionation similar to that of Tsuda. Determination of P_2O_5 in the various fractions was made by the colorimetric method of Deniges [1920] as modified by Truog and Meyer [1929]. The outline of the method adopted is given below schemetically.

The procedure of analysis was as follows :—

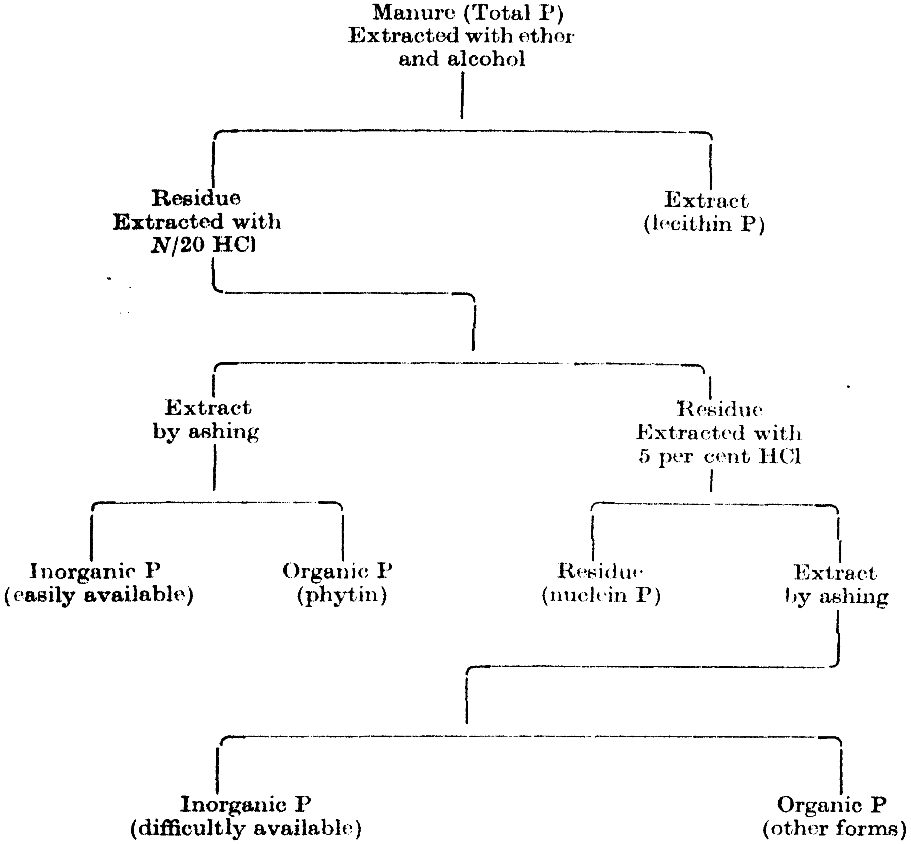
5 gm. of the material were extracted for 20 hours with ether in a soxhlet apparatus. The residue was similarly extracted with absolute alcohol for a period of 12 hours. The two extracts were mixed, evaporated to dryness and the P_2O_5 in the residue determined colorimetrically after gentle ignition. This represents phosphoric acid in the form of lecithin.

The residual material from the alcoholic extraction was dried and extracted with 200 c.c. of *N*/20 hydrochloric acid by shaking for two hours. The inorganic P_2O_5 was determined in an aliquot of the extract. The total P_2O_5 in the extract was determined by evaporating an aliquot with 2 c.c. of

---

*The work reported here was carried out at the Rothamsted Experimental Station, England.

10 per cent solution of magnesium nitrate and by igniting it gently. The ignited residue was treated with 1 c.c. of conc. hydrochloric acid, diluted with water to about 20 c.c., heated on a sand-bath for 15 minutes, made up to a known volume and P_2O_5 determined in an aliquot. The difference between total and inorganic P_2O_5 gave the organic phosphorus in the extract. The organic portion represents phytin and the inorganic portion represents easily available phosphorus.



The residue of the $N/20$ hydrochloric acid extraction was dried and again extracted with 5 per cent hydrochloric acid in the same way and its P_2O_5 both organic and inorganic, were determined as before. The inorganic phosphorus represents phosphorus in difficultly available form and the organic fraction represents combination other than lecithin, phytin and nuclein.

The last residue was dried and total P_2O_5 determined by ashing. This represents phosphoric acid in the form of nuclein.

The total phosphorus in the manure was obtained by summing all the fractions. An independent determination in the manure was found to agree, within experimental error, with the summation figure. The results are shown in Table I.

TABLE I

Fractions of P_2O_5 in organic manures expressed as percentage total P_2O_5

		Poultry manure* (dried)	Poultry manure (fresh)	Farmyard manure	Adco compost
P_2O_5 soluble in ether and alcohol		0·8	0·3	0·4	0·1
P_2O_5 soluble in $N/20$ hydrochloric acid	Inorganic (easily available)	40·5	43·3	68·5	26·3
	Organic phytin)	35·1	32·8	4·6	0·0
P_2O_5 soluble in 5 per cent hydrochloric acid	Inorganic (difficultly available)	4·2	4·5	7·2	66·3
	Organic (other forms)	12·7	12·1	5·0	1·1
P_2O_5 in the residue (nuclein) .		6·7	7·0	14·3	6·2
Total organic P_2O_5 . .		55·3	52·2	24·3	7·4
Total inorganic P_2O_5 . .		44·7	47·8	75·7	92·6

*Commercially prepared sample of dried manure

It will be seen from the table that the greater part of the phosphorus of poultry manure is in organic form, that 25 per cent of the phosphorus of farmyard manure is organic, whereas Adco compost has its phosphorus mostly in the inorganic form. Most of the inorganic phosphorus of the poultry manure and the farmyard manure was dissolved in the dilute acid (that is easily available to plants), whereas in the case of Adco compost about 70 per cent of the inorganic phosphorus was insoluble in dilute acid but was soluble in 5 per cent hydrochloric acid. This would mean that Adco compost is inferior to the natural manures so far as the availability of its phosphorus is concerned. Of the organic phosphorus compounds, phytin is the highest fraction in the poultry manure, whereas farmyard manure and Adco compost have their organic phosphorus mainly in the nuclein fraction. The high content of phytin phosphorus in poultry manure and its absence in Adco compost are readily understandable from the consideration that phytin is present in seeds and grains in large amounts (70-90 per cent of the total phosphorus is in this form) which constitute the major portion of the feed of these birds. Lecithin is present in small amounts in all these manures. It is also evident from the results that fresh and commercially prepared samples of poultry manure behave vary similarly and that kiln drying has not produced any appreciable change in the different fractions.

The very interesting fact that emerges out of this analysis is that about 70 per cent of the total phosphorus of farmyard manure is easily available to plants. The classical experimental plots at Rothamsted and Woburn offer an excellent field for testing this point further. For this purpose samples from the ' no-manure ', ' mineral ' and the ' dung ' plots were analysed for their content of available phosphorus and organic phosphorus. Available phosphorus was determined in a semi-normal acetic acid extract of the soil and the organic phosphorus in a quarter normal sodium hydroxide extract by the bromine oxidation method of Dean [1938] as modified by Ghani [1938].

The mineral manured Broadbalk wheat plots at Rothamsted received 3·5 cwt of superphosphate per acre annually since 1843, while that at Woburn (continuous Barley) received 3·5 cwt superphosphate per acre annually for the first 30 years and 3·0 cwt superphosphate per acre from 1907 to 1926. The dunged plots at Broadbalk received annually 14 tons of farmyard manure per acre containing an amount of phosphorus roughly equivalent to 3·5 cwt of superphosphate and that at Woburn the annual dressing was roughly equal to 2·5 cwt of superphosphate per acre. The results of analysis are shown in Table II.

TABLE II

Effect of the farmyard manure on the available phosphorus and the organic phosphorus of the soil

(Mg. P_2O_5 per 100 gm. soil)

Soil	Treatment	Acetic acid-soluble P_2O_5	Organic P_2O_5	*p*H
Rothamsted				
A 3957	No manure	Trace .	21	7·9
A 4279	Minerals .	40	20	7·8
A 3956	Dung .	54	30	7·5
Woburn				
A 3009	No manure	3	36	5·4
A 3003	Minerals .	16	32	5·8
A 3019	Dung .	27	48	5·8

It will be seen from the table that the acetic acid-soluble phosphorus in two soils which receive no manure is very small. The mineral manured plots, both at Rothamsted and Woburn give higher values for this fraction, while the two dunged plots give still higher values and in fact are outstandingly rich in the acetic acid-soluble fraction. This high availability figure is quite in keeping with the results obtained in the previous fractionation of the manure.

Considering the extra amount of farmyard manure, the Broadbalk plot received in the first 33 years (before experiment at Woburn was started) and the lesser amount of annual dressing in the last 20 years, it would appear that the accumulation of organic phosphorus due to the application of dung proceeds at a higher rate in the Woburn plot than in the Broadbalk plot. This suggests that organic phosphorus compounds are more stable under acid conditions due to consequent lack in microbial activities. This, together with the fact that acetic acid-soluble phosphorus in the Rothamsted plot is double that of the Woburn plot, further suggests that organic phosphorus of farmyard manure is more quickly mineralized in neutral soils than in acid ones.

SUMMARY

1. A quantitative study of the distribution of different forms of phosphoric acid in poultry manure, farmyard manure and Adco compost has been made.

2. The greater part of the phosphorus of poultry manure is in organic form ; phytin constitutes a major portion of its organic phosphorus and its inorganic phosphorus is present mostly in the available form. 75 per cent of the phosphorus of farmyard manure is inorganic, most of which is easily available. The Adco compost has its phosphorus mainly in the inorganic form of which the greater part is difficultly available. Lecithin is small in all the three manures, while nuclein is comparatively high in the farmyard manure.

3. Analyses of soils from the experimental plots at Rothamsted and Woburn show that application of farmyard manure maintains the available phosphorus status of a soil at a high level and that the organic phosphorus of farmyard manure is fairly quickly mineralized in neutral soils.

ACKNOWLEDGMENTS

The author wishes to acknowledge his thanks to the Director and staff of the Rothamsted Experimental Station for supplying the manure samples and for providing facilities for this work.

REFERENCES

Dean, L. A. (1938). *J. agric. Sci.* **28**, 234
Deniges, G. (1920). *Compt. Rend.* **171**, 802
Funatsu, T. (1908). *Bull. Coll. Agric., Tokyo. Imp. Univ.* **7**, 457
Ghani, M. O. (1938). *Ph. D. Thesis of the London University*, pp. 38 and 65
Truog, E. and Meyer, A. H. (1929). *Indis. Engen. Chem. Anal. Ed.* **1**, 136
Tsuda, S. (1909). *J. Coll. Agric. Tokyo* **1**, 167

DAMAGED LANDS IN THE DECCAN AND THEIR CLASSIFICATION*

BY

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(With Plates LXVII and LXVIII and seven text-figures)

THE Deccan tract can be classified into three main groups as under :—

(1) The Ghats
(2) The transition tract
(3) The Desh tract

The Ghats receive very heavy rainfall varying from 100 to 150 in. The transition tract receives from 20 to 30 in. of rain while the Desh on the eastern side receives rainfall varying normally from about 20 to 25 in. and is often frequented with famine. In order to relieve cultivators of their distress, Government constructed dams at suitable sites on the Ghats to serve as storage reservoirs. These dams are the Bhatgar dam feeding the Nira Left and Right Bank Canals to a length of about 100 miles. The Khadakvasla dam feeding the Mutha Canals, and the Bhandardara, Darna and Chankapur dams feeding the Pravara, Godavari and Girna Canals, respectively. Thus, the system spreads through the Poona, Sholapur, Ahmednagar and Nasik districts. Irrigation has done immense good to cultivators as they are now able to grow crops with minimum water charges without any risk. On the other hand, all concerned realize the increasing danger in the spreading of waterlogged and salt-affected lands. We can ascribe this formation due to the following causes :—

(*a*) Weathering and leaching of the parent rock
(*b*) Presence of salts in the soil profile
(*c*) Quality of irrigation water

(*a*) On account of the rapid changes in temperature, some of the minerals of the trap rock weather rapidly and the resulting ingredients are leached away to the low-lying areas. This is the chief reason for the formation of salt lands, [Mann and Tamhane, 1910].

(*b*) The soil profile contains salts in the accumulation horizon which, under conditions of high subsoil water-table resulting from heavy perennial irrigation, rise to the surface and deposit salts.

(*c*) The quality of irrigation water of all Deccan canals is excellent as the salts vary from 10 to 20 parts and rarely 40 parts per 100,000 parts and the *p*H values range from 7·0 to 7·50.

These results show that there is no possibility of formation of barren lands by using these waters alone for irrigation for any number of years.

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*Paper read on 7 October 1940 at the Symposium on 'Alkali Soils of the Deccan' under the auspices of the Indian Society of Soil Science with suitable modifications.

CAUSES OF RISE OF SUBSOIL WATER-TABLE

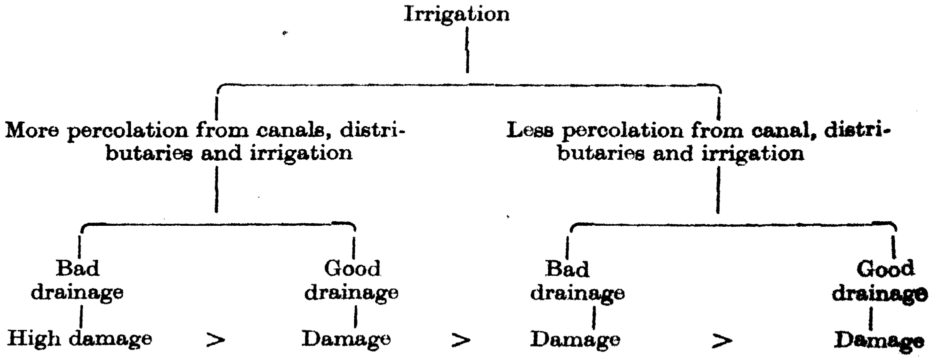
The canals generally pass through murrum cuttings in the ridges and in embankment in the valleys (to straighten as far as possible zigzag course of a falling contour) and as a result there is percolation through the banks. There is also percolation from the irrigated fields particularly through the shallower soils and this is incurred due to over-irrigation.

The percolation water from these sources passes into the subsoil and adds to the residual subsoil water raising its level. The subsoil water then moves through the pervious subsoils towards the valleys to find an outfall in the *nalla*. The subsoil water level consequently rises to form a gradient—sufficient to pass the discharge and where it reaches the surface, it causes water-logging, i.e. free water at the surface. Where owing to the relative impermeability of the intervening subsoils the rate of capillary rise of water through the soil is less than the rate of evaporation from the surface the salts from solution deposit on the surface and concentrate in the upper layers.

It will, therefore, be seen that damage results from surplus subsoil water which causes a rise in the subsoil water-table and evaporates from the surface. Hence, damage varies directly with the difference in quantity of water (discharge) passing into the subsoil and that coming out of the subsoil into the *nallas*.

Again, water passing into the subsoil is equal to the percolation from irrigation plus percolation from canals and distributaries. Water coming out of the subsoil, through *nallas* is proportional to the draining quality of the valley. It follows that there will be more damage with more irrigation, the drainage being constant, and less damage with better drainage, irrigation being constant.

This can be diagramatically represented as under :—


Irrigation
More percolation from canals, distributaries and irrigation
Less percolation from canal, distributaries and irrigation
Bad drainage
Good drainage
Bad drainage
Good drainage
High damage
>
Damage
>
Damage
>
Damage

There will be more percolation in catchments where there are larger areas under irrigation under comparatively shallower soils and less percolation with the same amount of irrigation in catchments having mostly deeper soils.

Similarly, percolation will be more from canal and distributary in murrum section than the soil section as murrum is more pervious to water than soil,

DAMAGE UNDER DECCAN CANALS

Table I will give an idea of the extent of damage on different canals. It will be seen that there is a considerable area under damage on each canal and in addition 1½ times the area under 4 ft. hydroisobath (equal depths of water from ground level).

TABLE I

Name of canal	Damaged area in 1928-30 in acres	Damaged area in 1938-40 in acres
Nira Left Bank	9,407	17,942
Nira Right Bank.	909	9,653
Godavari canals	17,000	25,047
Pravara canals	13,407	22,442

SCOPE OF RECLAMATION

These lands which are now spoiled were once very valuable, producing good crops. Their value can be put at Rs. 200 to Rs. 400 per acre in normal years, the price varying according to the proximity or otherwise of towns. This shows how important it is to tackle the problem and try to bring back these lands once again under cultivation. The first attempt, therefore, consists of providing drainage by laying pipes or providing open drains.

Subsoil drainage

As already stated, in the Deccan the canal starting from a pick-up weir follows a falling contour crossing several subsidiary ridges and valleys in its course.

The soils and the subsoils on the ridge slopes are usually open and pervious whereas those in the valley are more or less heavy and impervious. Hence, unless the pervious subsoil is continuous up to the natural *nalla*, drainage of the valley is rather difficult. If the pervious layer dips down below the existing *nalla* due to the silting of the old valley, as is common in the Deccan, drainage is blocked and an outfall to the subsoil water, entrapped in the pervious layer, has to be provided by artificial drains, connecting the pervious subsoil with the natural outfall at the lowest level possible. On this account, a drain passes partly through a pervious strata and partly through an impervious one. It is the former portion that actually drains the land and reduces water pressure acting in the area lower down ; whereas the drain in the latter portion merely carries water. Pipes are usually laid in the pervious portion whereas the drain in the carrier portion is kept open. For this purpose a very careful soil, subsoil and hydro-logical survey is carried out by means of levelling instruments, auger bores and dionic water tester. The scheme of drainage is carefully planned from this data.

Fig. 1 shows the scheme of drainage in the Manjri area, a village about 10 miles from Poona. It shows murrum isobath, damaged area and the natural *nalla*.

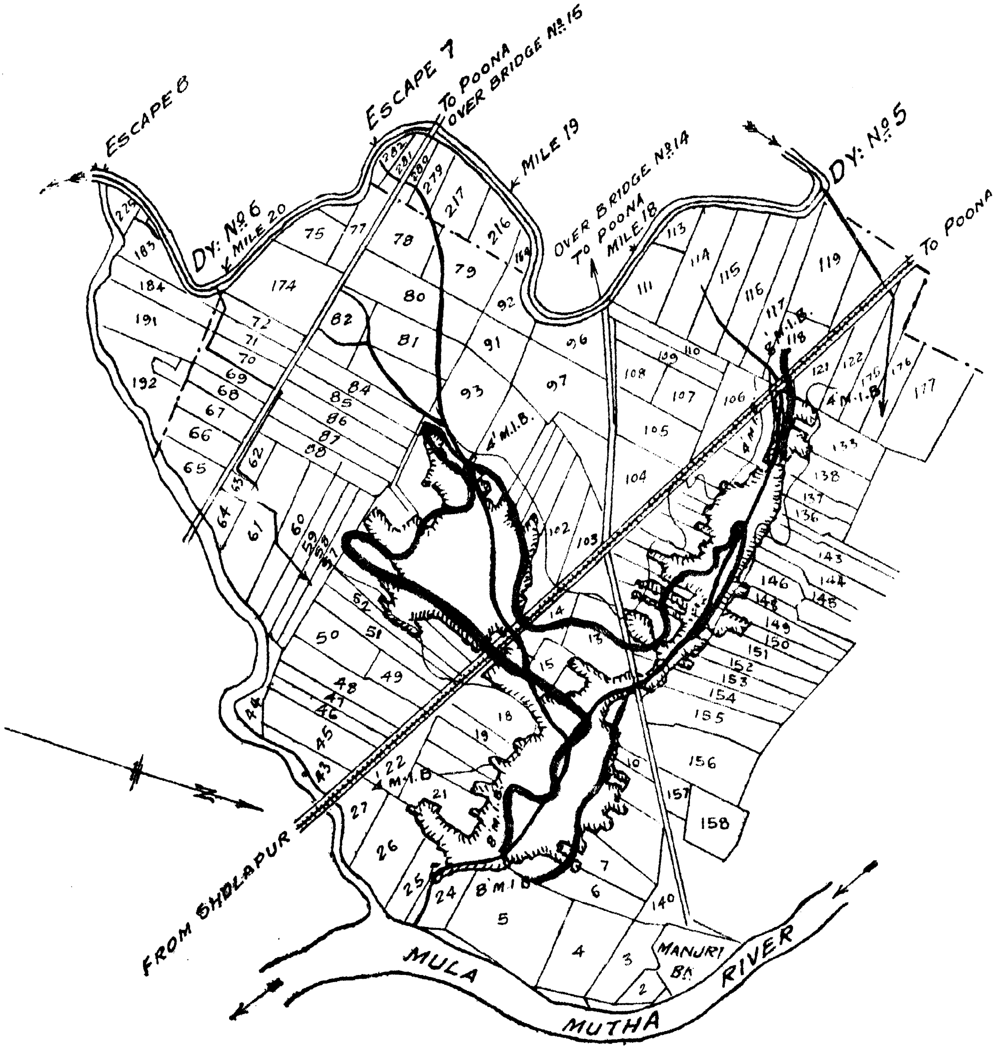


FIG. 1. Plan showing subsoil survey and damaged area classification and natural *nalla*, Mutha Right Bank Canal, Manjri Drainage Scheme (scale 1 in. = $\frac{3}{8}$ mile)
(Area enclosed in hatched line is all damaged)

Fig. 2 shows the same scheme as completed whereby the remnant subsoil water-table existed only as a very small fraction of what it was originally.

Plate LXVII, fig. 1 shows the operation of laying pipes in a drain, 5 ft. below ground level.

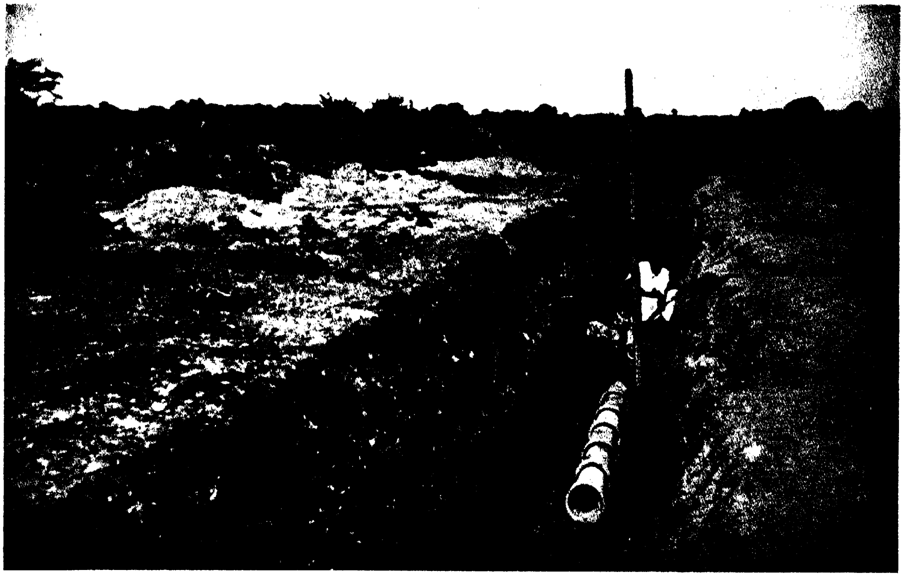


FIG. 1. Operation of laying pipes in a drain (Mark the top string in level with the ground)

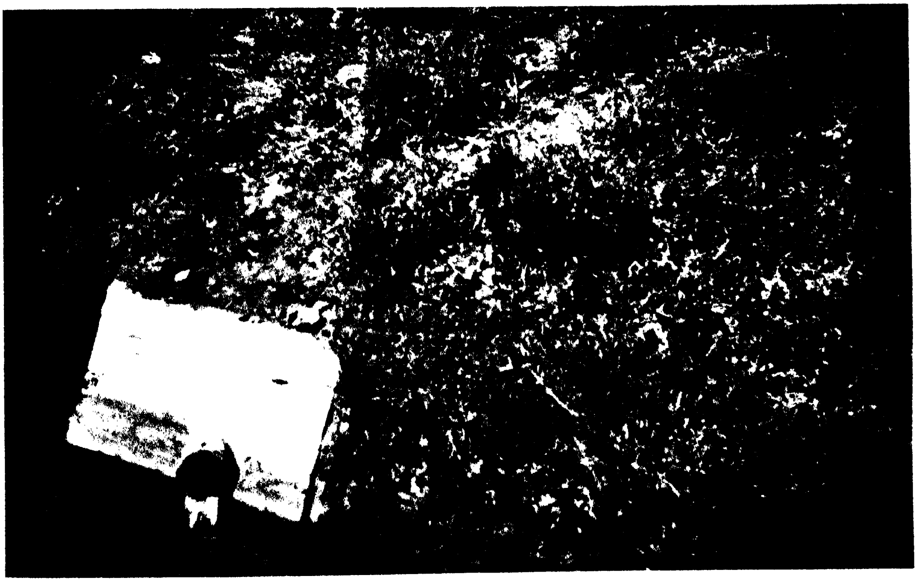


FIG. 2. Pipe-line after completion and discharging in open drain

Sugar cane crop. Local cane (Pundia). Tried in a mixed saline soil in S. No. 128, Baramati

(Promising crop 8-10 feet tall)

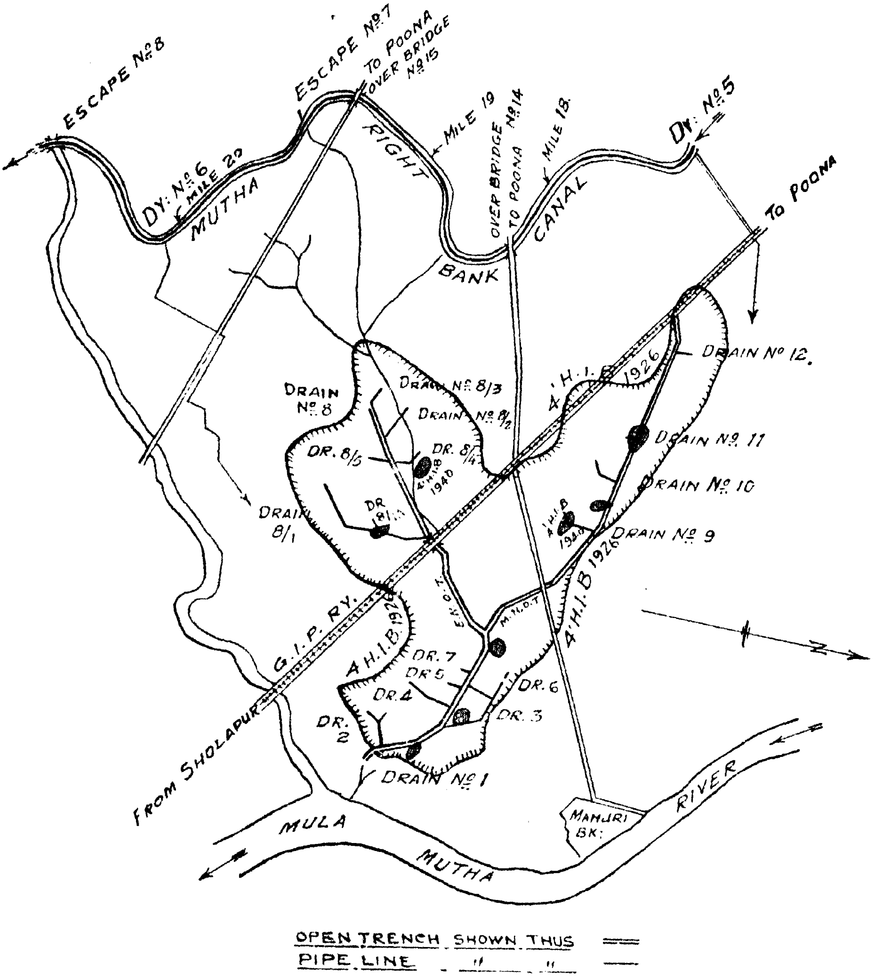


FIG. 2. Plan showing 4 ft. H. I. Bs. before and after drainage and drainage lines, open and closed (pipe lines), Mutha Right Bank Canal, Manjri Drainage Scheme (Scale 1 in. = ⅝ mile)

Plate LXVII, fig. 2 shows the same pipe line after completion and discharging in the open drain.

Detailed scientific work on drainage in the Deccan is described by Inglis and Gokhale [1927] and its engineering technique by Evershed [1937].

Reclamation

The next step is reclamation of the areas where the subsoil water-table is lowered as a result of drainage.

Soil scientists like Hilgard, Gedroiz, De Sigmond, Burgess and Breezeale and others have tried various fertilizers and recommended use of gypsum. Marr [1927] describes also the role of CO_2 in alkali reclamation. In India, the science of reclamation is gradually developing. Taylor and Puri [1935] of the Punjab Irrigation Research Institute suggest the following :—

(a) By a suitable crop rotation in which rice is used as an agent for decomposing the sodium clay
(b) The application of gypsum which introduces sufficient calcium ions in solution to prevent the base-exchange reaction between sodium salt and a calcium clay

Dr Dhar has proposed a new method of reclamation of alkali soil by applying molasses varying from 100 to 500 maunds to as high as 1,000 maunds per acre. This, when added to alkali soils and watered, converts alkali soils into acidic ones. At present it has scope only near the sugar factories. Besides, the cost is prohibitive as in the Deccan the rates quoted are eight annas per maund.

Coming to the Deccan, Mann and Tamhane [1910] have described salt lands in the Nira valley. Their work deals with the salts found in the valley in a very general way. Since this publication, our knowledge on salt lands is much advanced which is put up in this paper.

DAMAGED LANDS AND THEIR CLASSIFICATION

It is mentioned that there is an extensive area under damage amounting to about 75,000 acres with almost an equal area where water-table is within 4 ft. from ground level. Out of this, one third area is damaged due to water-logging and the remaining area is damaged due to salt as a result of capillary action from high saline subsoil water-table.

The soil types beginning from coarse soils and medium black soils are not damaged as the deep black soil for the simple reason that they are in the upper reaches or on the ridges. If we measure maximum slope of the different soils at right angles to the contour, we find in normal catchments that the coarse soils have slopes below 1 in 60, the murrum black soils have slopes below 1 in 100 and the deep soils have slopes below 1 in 300 with a fall of say 35 ft. or more from coarse soil to deep soil.

Fig. 3 gives an idea of the usual slope of these soil types. This is a very dominant factor in causing damage.

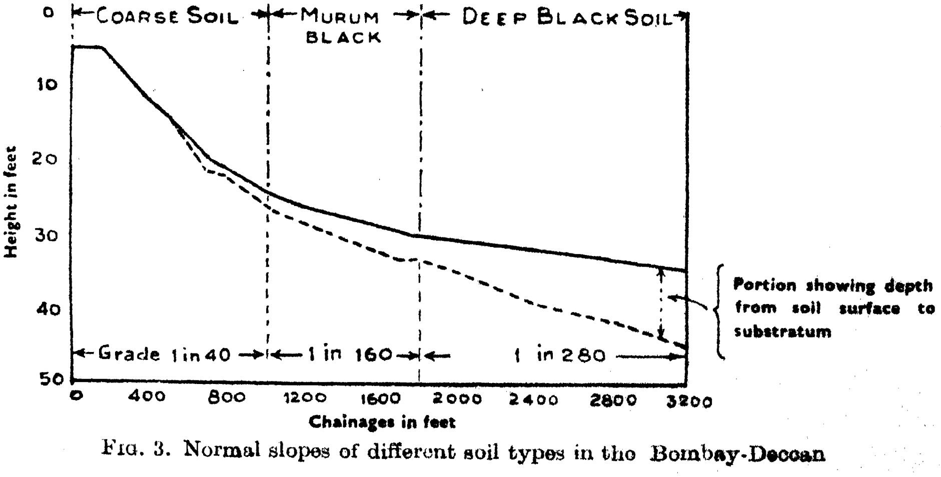


FIG. 3. Normal slopes of different soil types in the Bombay-Deccan

In order to see the actual field conditions of salt distribution several soil profiles were examined from deep soil areas. Analysis of a typical one is given in Table II.

TABLE II

Results of saline profile from deep black soil type

Serial No.	Ingredients	Depth of soil					
		0—6 inches	6—12 inches	1—2 feet	2—3 feet	3—4 feet	4—5 feet
1	Total soluble salts	3·11	2·28	1·82	1·62	1·14	0·85
		Percentage on total salts					
2	$CaCO_3$	0·93	2·58	4·61	5·60	5·98	6·84
3	$CaSO_4$	29·04	24·59	12·82	8·08	5·25	6·51
4	$MgSO_4$	14·70	13·43	17·31	15·37	19·31	11·79
5	Na_2SO_4	39·57	44·85	48·49	51·44	49·45	53·66
6	NaCl	12·30	16·50	12·18	15·90	16·34	13·75
7	*p*H values (colorimetric) . .	7·50	7·70	8·00	8·30	8·50	8·65

The results show that the soluble salts consist of mixed salts of calcium, magnesium and sodium. The percentage of sodium salts on the whole shows a tendency to increase with depth.

Similarly several other damaged profiles were examined. Analysis of typical one is given in Table III.

TABLE III

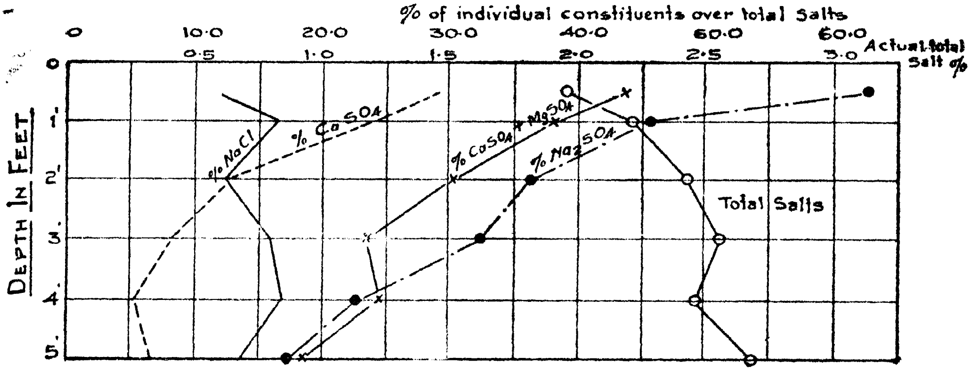
Results of saline soil profiles from deep grey soil type

Serial No.	Ingredients	Depth of soil						
		0—6 inches	6—12 inches	1—2 feet	2—3 feet	3—4 feet	4—5 feet	7—8 feet
1	Total soluble salts .	2·49	1·23	1·30	1·40	1·18	0·86	0·08
		Percentage on total salts						
2	$CaCO_3$	1·63	4·43	5·53	5·08	5·35	5·48	6·19
3	$CaSO_4$	6·03	0·15	2·0	0·96	...	...	...
4	$MgSO_4$	2·71	6·12	9·0	5·57	10·08	13·87	4·95
5	$MgCO_3$	1·49	2·33	1·27	3·22	4·15	4·63	4·37
6	Na_2SO_4	60·37	57·79	49·74	49·55	48·41	45·57	51·47
7	NaCl	24·56	27·13	28·48	30·46	28·65	29·79	32·00
8	*p*H values (colorimetric)	8·60	8·58	8·72	8·73	8·77	8·93	9·15

It will be seen that the total salts consist mostly of sodium salts. The calcium and magnesium salts are practically negligible. The *p*H values are on the higher range than those observed in case of the previous profile. Fig. 4 shows the total soluble salts and percentage of different ingredients over total salts in both the types of soils.

Soil profiles containing mixed salts of calcium and sodium were collected and leached of excessive salts. The residual soil was tested for exchangeable bases and other tests with the results given in Table IV

MIXED SALINE PROFILES



SALINE PROFILE

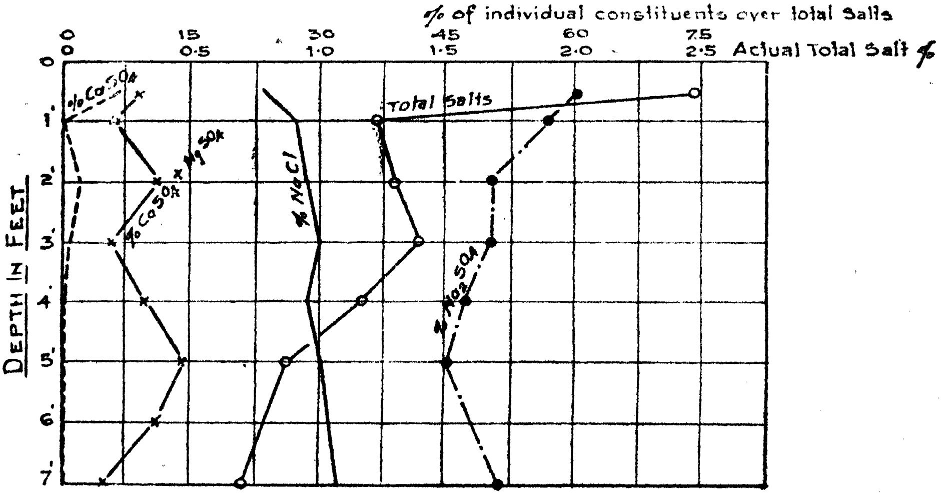


Fig. 4. Percentage of individual constituents over total salts

TABLE IV

Results of soil tests of mixed saline type

Depth	Total* bases milli-equivalents per cent	Per cent monovalent bases to total bases	Capillary rise (cm.) 300 minutes In water	Capillary rise (cm.) 300 minutes In NaCl	pH values† in Distilled water	pH values† in N-KCl	Original total soluble salts (per cent)
I							
0—6 in.	24·92	3·74	3·0	5·9	8·26	7·89	3·64
6—12 in.	24·57	4·89	3·1	6·3	8·28	7·80	1·59
1—2 ft.	24·40	8·02	4·3	6·3	8·46	7·44	0·95
2—3-ft.	24·99	4·04	3·3	4·5	7·94	7·42	1·25
3—4 ft.	23·53	11·57	3·6	4·9	8·02	7·28	0·19
5—6 ft.	26·82	14·01	4·1	5·3	8·04	7·18	0·75
II							
0—6 in.	21·94	1·54	7·8	8·0	7·40	6·96	3·40
6—12 in.	21·56	2·54	3·4	7·2	8·00	7·36	1·04
1—2 ft.	19·05	1·12	2·6	6·3	8·30	7·40	2·64
2—3 ft.	17·91	1·20	2·2	4·7	8·60	7·42	2·28
3—4 ft.	19·18	11·10	1·9	3·7	8·30	7·56	2·10
4—5 ft.	19·66	9·97	2·0	3·4	8·40	7·57	2·64
6—6·5 ft.	...	...	No rise	5·7	9·24	7·62	0·56
III							
0—1 ft.	24·34	11·62	3·0	13·1	8·46	7·57	3·24
1—2 ft.	22·38	14·88	8·4	12·1	8·34	7·64	2·24
2—3 ft.	19·38	10·12	3·2	5·2	8·66	7·56	2·07
3—4 ft.	20·06	15·89	2·7	6·5	8·76	7·57	1·61
4—5 ft.	20·69	31·68	2·6	8·0	9·54	7·64	0·82

*Exchangeable bases were estimated by Puri's method [1935, 1, 2]

†pH values were found out by antimony electrode standardized by Puri [1932]

The results of replaceable bases show that the total bases consist of over 95 per cent of divalent bases for top foot of soil, with very low percentage of monovalent bases. The capillary rise shows a fairly good rise throughout. The pH values are also low like normal soil profiles of the same type. Fig. 5 clearly illustrates these results.

Similarly, a number of alkali soil profiles where subsoil water level was reduced, were examined. Results of only typical ones are reproduced below :—

ALKALI PROFILE NO. A

This was collected from fine black soil just below murrum black soil. The analysis of water-soluble salts will be clear from Table V.

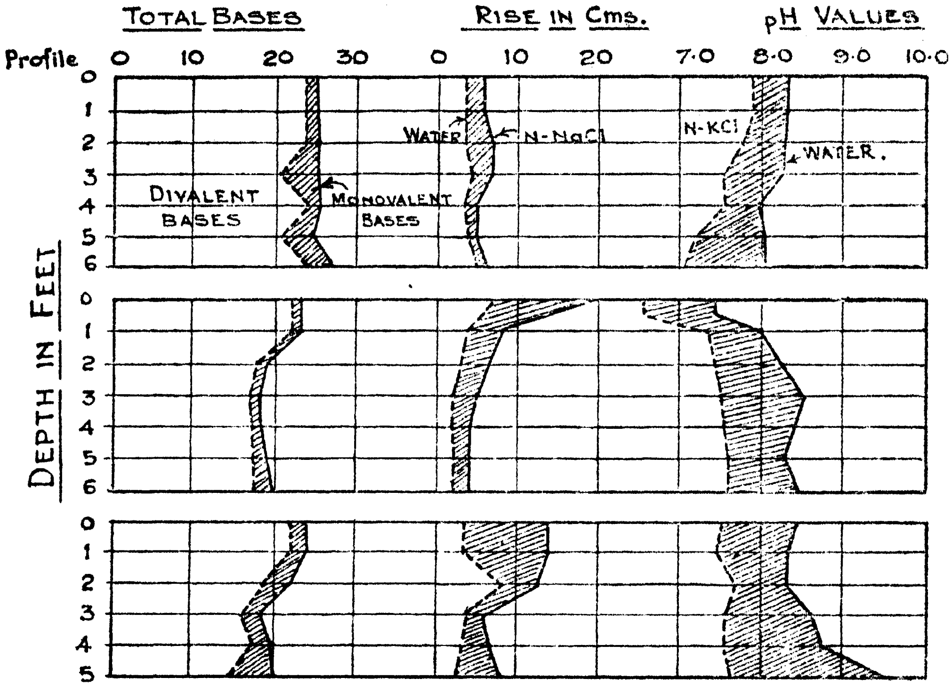


Fig. 5. Showing soil tests in mixed saline soil profile

TABLE V

Results of water-soluble salts of sodiumized fine black soil

Serial No.	Depth of soil	Total soluble salts (per cent)	Na_2CO_3 (per cent)	Other carbonates (per cent)	Chlorides (per cent)	Sulphates (per cent)	Calcium (per cent)
1	0—6 in.	0·24	In Traces only	0·116	0·018	0·131	0·016
2	6—12 in.	0·30		0·130	0·037	0·131	0·080
3	1—2 ft.	0·34		0·072	0·037	0·098	*Nil*
4	2—3 ft.	0·58		0·072	0·037	0·301	0·066
5	3—4 ft.	0·20		0·130	0·018	0·049	0·016
6	4—5 ft.	0·22		0·086	0·018	0·107	0·008

The total salts gradually show a tendency to increase. The maximum concentration is at the 3rd foot. After that they get lowest. The predominant salt is sulphate. This salt more or less fluctuates in the same way as the line of total salts. The carbonates are next to it and then calcium salts. Magnesium is in traces. The study of exchangeable bases of the whole profile with capillary rise and *p*H values are given in Table VI.

TABLE VI

Results of different soil tests of sodiumized fine black soil

Serial No.	Depth of soil profile	Total bases milli-equiv. (per cent)	Per cent mono-valent bases to total bases	Capillary rise in cm. in 300 minutes		pH values in		$CaCO_3$ (per cent)
				In water	In NaCl	Distilled water	*N*-KCl solution	
1	0—6 in. . . .	26·84	20·16	2·10	10·9	9·14	7·28	11·95
2	6—12 in. . . .	24·33	22·97	1·70	8·8	9·50	7·28	13·75
3	1—2 ft. . . .	27·87	19·25	2·00	7·9	9·44	7·32	12·60
4	2—3 ft. . . .	25·12	15·44	2·00	11·2	9·45	7·04	11·20
5	3—4 ft. . . .	25·78	13·31	2·10	6·10	9·46	7·10	15·60
6	4—5 ft. . . .	23·71	20·55	1·70	6·1	9·48	7·44	14·00

The predominant base is replaceable calcium, constituting about 80 per cent of the total bases. The monovalent bases range from 13 per cent to as high as 22 per cent. The capillary rise is also very low while the *p*H values are above 9·0.

ALKALI PROFILE No. B

Another typical profile was examined from stiff alkali spot from deep soil area with the results given in Table VII.

TABLE VII

Results of water-soluble salts and other tests

Depth of profile	Total salts (per cent)	Na_2CO_3 (per cent)	$NaHCO_3$ (per cent)	Chlorides (per cent)	Sulphates (per cent)	*p*H values in		Per cent monovalent bases to total bases
						water (distilled)	*N*-KCl solution	
0—6 in. . .	0·21	0·084	0·066	0·018	0·024	10·09	7·68	40·76
1—2 ft. . .	0·52	*Nil*	0·231	0·055	0·207	10·08	7·57	52·81
2—3 ft. . .	0·47	*Nil*	0·199	0·018	0·237	9·98	7·74	53·57
3—4 ft. . .	0·41	0·042	0·221	0·018	0·121	10·08	7·78	77·33
4—5 ft. . .	0·41	0·084	0·177	0·028	0·098	9·76	7·80	53·42

The salts are comparatively more than the previous profile and have concentrated at the 2nd foot. The carbonate salts are very high. The *p*H values are nearly up to 10·0 while the per cent monovalent bases are found to the extent of 40 per cent increasing up to 77 per cent at the 3rd to 4th foot soil column.

ALKALI PROFILE No. C

Profile from an intensely stiff alkali patch was examined further and gave the results given in Table VIII.

TABLE VIII

Results of water-soluble salts and other tests

Depth of soil	Total salts (per cent)	Na_2CO_3 (per cent)	$NaHCO_3$ (per cent)	Chlorides (per cent)	Sulphates (per cent)	*p*H values in		Per cent monovolent bases to total bases
						Distilled water	*N*-KCl solution	
0—1 ft. . .	0·42	0·086	0·088	0·037	0·185	10·20	7·64	62·48
1—2 ft. . .	0·53	0·056	0·133	0·055	0·265	9·80	7·52	50·20
2—3 ft. . .	0·83	0·056	0·087	0·074	0·595	9·60	7·54	38·38
3—4 ft. . .	0·95	0·028	0·111	0·074	0·720	9·64	7·54	35·65
4—5 ft. . .	0·31	0·028	0·155	0·055	0·197	10·10	7·82	65·73

In this profile the salts are increasing up to 4th foot after which there is sudden fall. The predominant salt is sulphate throughout the profile unlike the previous profiles. The secondary salts are carbonates. Chlorides are in very low quantities. The *p*H values are about 10·0 while the top foot is highly sodium saturated.

Mechanical analysis of these damaged soils profiles indicated that the B horizon was coarser than the top horizon.

CLASSIFICATION OF DAMAGED SOILS

Mixed saline soils

The first type of profiles wherein we find mixed salts of calcium and sodium and which on leaching give characteristic low *p*H values like normal soils and fairly high percentage of divalent bases can be termed mixed saline soils.

Saline soils

The next type of profiles examined consist mostly of sodim salts only with *p*H values on the higher range than mixed saline soils. These represent accumulation of salts under high water-table and are not leached either naturally or artificially. These we will call saline soils.

Alkali and strong alkali soils

Further profiles are alkali types wherein leaching conditions are established. The total salts are thus low at the top. These are stiff soils containing varying degrees of alkalization from 20 to as high as 50 to 60 percent. We find *p*H values over 9·0 and sometimes up to 10·0 with carbonate salts in great predominance ; we will call these alkali and strong alkali soils.

We have thus the following classes of the damaged soils :—

(*i*) Mixed saline soils
(*ii*) Saline soils
(*iii*) Alkali soils—Strong alakali soils
(*a*) (*b*)

Illustration.—A careful study was made in a Government area known as Experimental Salt Area stationed at Baramati commanded by Distributary 24-25, Nira Left Bank Canal. About 300 representative soil samples were collected and *p*H values, capillary rise and soluble salts were estimated (Fig. 6).

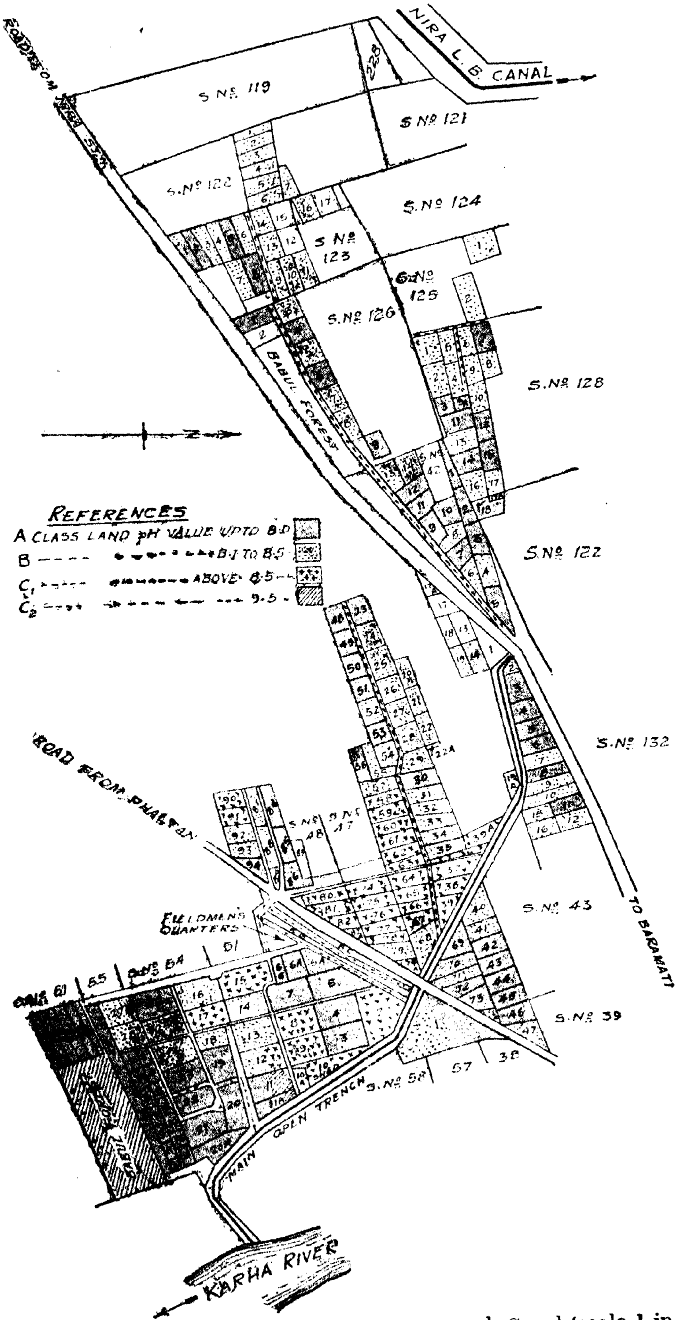


FIG. 6. **Experimental salt land, Baramati**: Nira Left Bank Canal (scale 1 in. = 1,100 ft

The whole area had salts varying from about 2 per cent to 4 per cent and more. It was noticed that on leaching certain plots, which had combined salts of calcium, magnesium and sodium, became free of excess of soluble salts rapidly and showed *p*H values up to 8·0. There were certain other plots in which soluble salts went down similarly but *p*H values were up to 8·5. Such gradations were noticed further, which is clearly illustrated in the figure. From the above description and the exhaustive tests of *p*H values, the damaged soils can be further classified as under :—

	Class of valuation
(1) High salts (which on leaching give low *p*H values up to 8·0) . .	A
(2) High salts (which on leaching give medium *p*H values up to 8·5) .	B
(3) High salts (without leaching) ; *p*H values above 8·5 . . .	C
(4) Low salts ; high *p*H values above 9·0	C_1
(5) High salts ; high *p*H values above 9·5	C_2

A reference may be made to the classification of damaged soils by De' Sigmond [1927] on the basis of sodium carbonate and total salts but the above classification has been found to be more suitable to Deccan conditions as actual tests of soil extract of even C_1 or C_2 types show very little alkalinity to Phenolphthalein. On the other hand, it is both rapid and precise to characterize alkali soils on the basis of *p*H values as mentioned above.

PRACTICAL APPLICATION

If the damaged soil falls under class A, it means that the soil can be improved by drainage and simple leaching (either natural or artificial).

It is shown that sodiumization does not take place in such soil profiles due to sufficiently high concentrations of calcium and magnesium salts side by side with sodium salts.

To improve such soils the procedure will be as under :—

First step

Level the land and prepare it into small plots according to the slope of the lands and leach the excessive salts.

Second step

Take a test crop of ***shalu jowar.*** This is a sensitive crop and is a useful practical guide in this leaching process. If it is an 8—10 anna crop we can make out that the salt concentration is sufficiently lowered. This crop is then followed by a green manuring crop next season followed by sugarcane.

Plate LXVIII shows the first cane crop taken after leaching operations in a mixed saline soil of A type in survey No. 128 of Experimental Salt Area, Baramati. This shows how easy it is to reclaim such types of areas.

Improvements of damaged soils under class B will be on the same lines as A but this may require leaching over two seasons on account of comparative lower concentration of calcium and magnesium.

Improvement of C type is a different process because if leaching is done ke types A and B, the soils may turn into types C_1 or C_2 and will be still difficult to reclaim. Improvement of these particular types require great skill which consists of addition of calcium fertilizers, sulphur, etc. along with farm yard manure. One such complete experiment is described.

Lysimeter experiment

Lysimeters of cement concrete were constructed in the midst of cane area in order to ensure proper 'cane atmosphere' to the cane grown in lysimeters. The lysimeters were rectangular in shape and measured 6 ft × 3 ft × 6 ft. Stiff alkali soil* was refilled in the lysimeter keeping the relative arrangements of layers the same as under natural conditions and with the same packing over a sloping bed of coarse sand 1 in. thick. This admitted drainage from the overlying soil layers. It was possible in lysimeters to carry out experiments under fully controlled conditions. Co 290 variety of cane was planted on 1 March 1938. The treatments given were as under :—

	Dose	Approximate cost (Rs.)
(1) Gypsum	3 tons per acre	75
(2) $CaCO_3$	3 tons per acre	70
(3) Sulphur	1/2 ton per acre	70
(4) Blank or control	. . . .	*Nil*

Farm yard manure at the rate of 15,000 lb. per acre was applied as a basal dose before planting. Three top dressings of ammonium sulphate and cake were given till the time of earthing up on the basis of 225 lb. of nitrogen.

Irrigation was given at an interval of 10 days and drainage was collected three days after irrigation was applied.

Results

The total water added was about 125 in. Gypsum treatment gave more drainage water than the rest of the treatments while sulphur stood second. This will be clear from Table IX.

TABLE IX

Drainage water received under different treatments

	Gypsum	Sulphur	$CaCO_3$	Blank
Drainage water in inches . . .	42·08	38·12	37·04	24·68
Percentage of drainage received to total water added.	29·64	26·36	26·12	17·36

***pH 9·0 ; soluble salts 0·55 per cent ; capillary rise 2·8 cm. in 300 minutes**

The drainage water was tested for total soluble salts and *p*H values and it was noted that gypsum and sulphur removed larger quantities of salts than the rest. The *p*H values of drainage water showed it to be more alkaline during July to December than during the rest of the year (Fig. 7). This was

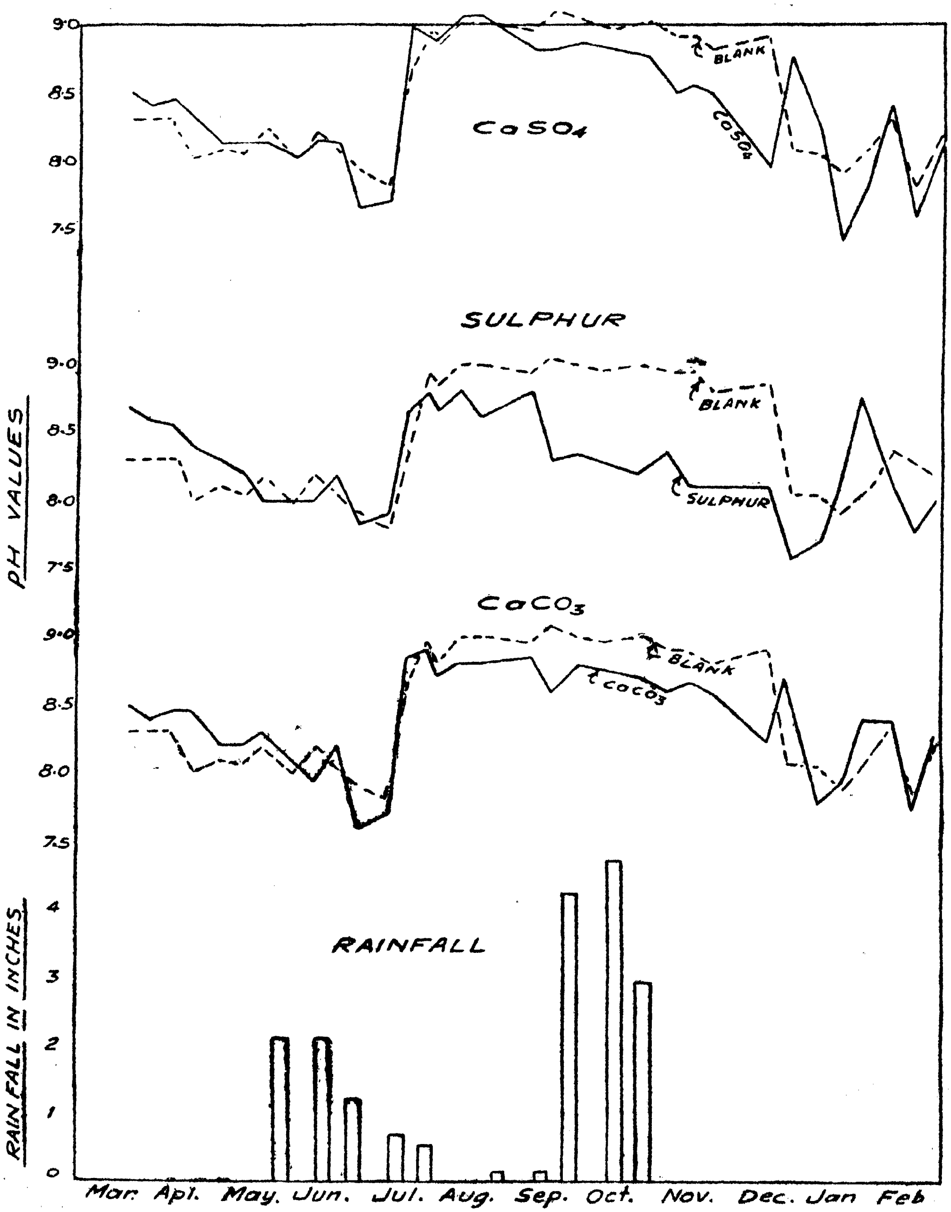


FIG. 7. Graph showing *p*H values of drainage waters in lysimeter

due to more dilution and consequent reduction in the conductivity of drainage water. The drainage water from the 'blank' was more alkaline than that from the treatments, but the quantity was much less. The crop was poor in the beginning but made a fairly good progress after earthing up. The total heights of cane under each treatment at the time of harvest and other relevant data are given in Table X.

TABLE X

Data of sugarcane harvested under different treatments

Treatment	Height of cane	Weight of cane in lb	Brix of juice	Purity of juice	Conductivity of juice
Sulphur	5 ft. 9 in. .	30	17·87	82·8	8,500
$CaSO_4$	6 ft. 2 in. .	30	17·87	82·5	7,500
$CaCO_3$	5 ft. 8 in. .	25	17·87	78·4	9,000
Blank	5 ft. 2 in. .	10	16·87	78·2	9,000

The results show the growth and quality of cane under each treatment. Sulphur and $CaSO_4$ are outstanding from this point of view. Results of soil profiles examined after harvesting cane are given in Table XI.

TABLE XI

*pH values of residual soil at different depths**

Original soil *p*H	Depth (inches)	Sulphur *p*H	$CaSO_4$ *p*H	$CaCO_3$ *p*H	Blank *p*H
8·90	0—6	7·44	7·72	7·56	7·56
	6—12	7·36	8·20	7·68	7·94
9·00	12—18	7·76	7·98	7·98	*8·39*
	18—24	8·24	*8·24*	*8·54*	9·12
9·10	24—30	8·42	8·96	8·84	8·49
	30—36	8·00	9·52	9·24	8·60
9·00	36—42	8·14		9·49	9·49
	42—48	*7·70*	9·00	9·49	9·00

* Figures in italic indicate the depth to which improvement progressed

It is seen that sulphur treatment improved the whole profile. Gypsum and $CaCO_3$ affected improvement up to 24 in while in ' blank ' (with cane) the soil improved up to 18 in. only.

FIELD EXPERIMENTS

Plot scale experiments were laid out to study the behaviour of different varieties of cane in lands in process of reclamation.

Preparatory tillage and doses of manure were according to the standard practice. But planting was done on sides of ridges and soils were stirred every month till the time of earthing up. Several stools were collected and observations on conductivity, sucrose content and total solids were taken in certain cases from juice. The results are given in Table XII. The tendency is a fall in sucrose with increase in conductivity. This shows that we may get a little inferior gull from lands in process of reclamation.

TABLE XII

Results of conductivity and sucrose of different varieties tried in alkali soils

Serial No.	Variety	Conductivity of juice by Dionic water tester	Sucrose (per cent)
1	POJ 2878	2500	17·58
2	POJ 2878	3000	18·83
3	Co 290	5500	14·29
4	Co 290	4250	15·72
5	Pundia (local cane)	2500	17·87
6	HM 320	2500	16·27
7	HM 320	5000	16·49
8	EK 28	2800	17·77
9	EK 28	3500	17·96
10	POJ 2883	3500	15·77
11	POJ 2883	4500	15·93
12	Co 360	2500	17·94
13	Co 417	5500	14·89
14	Co 419	4700	15·23

Detailed results of field experiments on varieties from which the above observations were taken are given below :—

The experiment was carried out in replicates and on randomized basis and results were treated statistically.

	Pundia	POJ 2878 III	POJ 2883	EK 28	HM 320 II	Co 290 I
Mean yeild of 4 replicates (tons per acre)	11·73	24·00	19·77	20·04	25·94	40·13
Difference	...	12·27	8·04	8·31	14·21	28·40

Significant figure 8·25 tons.

The results show that Co 290 stands first. Statistical treatment showed it to be significantly higher than Pundia : POJ 2878 and HM 320 stand next in order.

SUMMARY OF RESULTS

The Deccan soils have four types of damaged soils excluding waterlogged areas.

(1) Mixed saline soils.
(2) Saline soils.
(3) Alkali and strong alkali soils.

These require different treatments for their improvement. The first type merely improves by leaching while the saline soils get alkaline either under natural or artificial conditions of leaching and require fertilizers for their improvement. Gypsum and sulphur in combination with farm yard manure have been found to be the best. As regards cropping Co 290 sugarcane variety has proved to be alkali resistant and is tried after Dhaincha (Sesbania Aculeata) green manuring with a basal dose of gypsum and farm yard manure.

There is a great field for use of gypsum as there are extensive deposits of this stuff in the Deccan.

ACKNOWLEDGEMENT

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REFERENCES

De'Sigmond, A. A. G. (1924). Univ. Calif, *Hung. alk. soils and methods of their reclamation* **59**
Evershed, W. A. (1937). *Bombay P. W. D., T. P.* **56**, 28
Inglis C. C. and Gokhale, V. K. (1928). *Bombay P. W. D., T. P.* **24**, 7 ; 47
Mann, H. H. and Tamhane, V. A. (1910). *Bull. Bombay Dept. Agric.* **39**
Marr, J. C. (1927) *Agric. Eng. Rec. of Alk. Lands* **9**, 241
Puri, A. N.(1932). *Irrig. Res. Inst. Punjab* **4**, No. 4
————(1935, 1). *Soil Sci.* **2**, 159
————(1935, 2). *Soil Sci.* **3**, 383
Taylor, E. M. and Puri, A. N. (1935). *Punjab Irrig. Res. Inst.* **1**, 11

STUDIES ON PHYSICO-CHEMICAL CHANGES IN BLACK COTTON SOIL DURING NITRIFICATION*

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THE black cotton soil, more commonly known as regur soil, from the Malwa plateau (e.g. field No. 45 at the Institute of Plant Industry, Indore, Central India, from which soil for the present investigation was collected) has a very high clay content and a high base exchange capacity. The nitrogen balance of the soil during summer and the nitrification of the added inorganic and organic nitrogen has been studied by Wad and coworkers [1936, 1937, 1938]. Very little attention, however, appears to have been paid to the study of the physico-chemical properties of this soil, following treatment with ammonium sulphate. It is probable that such a study may throw light on the question, whether the changes in the tilth of the soil during crop growth are in any way related to nitrification. In the present investigation an attempt has been made to study some properties of the black cotton soil as nitrification proceeds in the untreated soil and in soil treated with two different doses of ammonium sulphate.

EXPERIMENTAL

Material and methods

The technique used was essentially that described by Wad and Panse [1933]. Soil, evenly graded (Table I) by passing through 1 mm. sieve was uniformly filled in galvanized iron trays 12 ft. × 6 ft. × 2 ft., after moistening it with only about 1/3 of the total water added. The water content was then made-up-to about 26-27 per cent, as it has been found by Plymen and Bal [1925] that under these conditions soil shows the maximum nitrifying activity. The addition of water was done by means of a fine light jet.

The rates of the treatments given were (*i*) 25 lb. and (*ii*) 50 lb. of N-equivalent of ammonium sulphate (Merck's A. R. quality) per acre of 6 inch deep soil. The trays were arranged in blocks with treatments randomized in two well ventilated chambers with glass doors. Daily temperature and humidity changes occurring during the experimental period were recorded. The experiments were conducted for a period of four months, during the Bombay monsoon, at this institute. Samples were taken out five times, starting with the initial, with about four weeks' interval and there were four repetitions for each of the above ; this has been found necessary for the statistical examination of results. Thus 3 × 5 × 4, that is, 60 trays were employed for the experiment.

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* Part of a thesis submitted by the junior author and accepted by the Bombay University for the degree of Master of Science.

Samples, 12 at a time, were removed on 11 August 1939 (initial), 12 September, 10 October, 13 November and 12 December. They were analysed (*a*) every month for ammoniacal nitrogen, nitrate nitrogen, organic carbon, C/N ratio and hygroscopic moisture ; and (*b*) every two months for base exchange capacity, total and individual replaceable bases, available phosporic acid (P_2O_5), aggregate analysis and resistance to water (structure coefficient).

Analytical methods

1. Ammoniacal nitrogen was determined by distilling 1 : 30 soil solution with MgO (5 gm.), absorbing the liberated ammonia gas in standard acid, and titrating back the remaining acid.
2. Nitrates were determined by the phenol-disulphonic-acid method.
3. C, N and C/N ratio were determined by Maclean-Robinson's method with slight modifications wherever necessary.
4. Hygroscopic moisture was determined by keeping the soil over 50 per cent humidity as done in Puri, Crowther and Keen's method.
5. Available P_2O_5 was determined in 1 per cent citric acid extracts followed by Pemberton's volumetric method.
6. Exchangeable calcium, magnesium, sodium and potassium and exchange capacity were determined by Puri's ammonium carbonate method, modified for calcareous soils [1935, 1936].
7. Mechanical analysis (of water dispersed and mechanically dispersed soil) was carried out by Bouyoucos' method [1934]. Structure coefficient (S. C.) as postulated by Russell [1938] was calculated from the relation—

$$\text{S. C.} = \frac{D-S}{D} \times 100$$

where D = per cent material > 0·05 mm. as obtained by mechanical dispersion.

S = per cent material > 0·05 mm. as obtained by water dispersion.

RESULTS

The results of analysis of the graded soil used for this investigation are given in Table I.

TABLE I

	Unsieved portion				Sieved portion
——	Plant residue	Rock fragments	Kankar 1·5—0·5 cm.	Murrum 0·5—0·15 cm.	0·1 cm.
Top loose earth 0—2 in.	0·2	0·4	2·1	9·2	88·1
Lower compact earth 2—6 in.	0·0	1·0	2·0	27·0	70·0
Average . . .	0·1	0·7	2·05	18·1	79·05

It will be seen from the above table that the soil formation processes are most active within two inches from the surface. The amount (about 90 per cent) of fine soil material (sieved portion) in this region is much greater than in the lower compact soil.

The results of complete chemical and physical analysis of the sieved soil used for the experiment are given in Table II. All the results are expressed on oven-dried basis.

TABLE II

Chemical and physical analysis of the sieved soil

(*i*) Gm. in 100 gm. of soil

Silica SiO_2	57·090
Al_2O_3	13·616
Fe_2O_3	8·674
CaO	3·633
MgO	2·897
K_2O	0·821
Na_2O	0·451
Loss on ignition	10·387
Total	97·569

Ratios—

SiO_2/Al_2O_3	4·193
SiO_2/R_2O_3	2·56

(*ii*) Mg. in 100 gm. of soil

Ammoniacal N	4·19
Nitrate N	0·6474
Total N	73·0
Organic carbon	499·0
Available P_2O_5	13·3
Available K_2O	0·4829

Ratio C/N = 10·10

(*iii*) Milli-equivalents per 100 gm. soil

Base exchange capacity	60·87
Total exchangeable bases	64·72
Exchangeable calcium	93·93 per cent of total bases
Exchangeable Mg.	5·359 per cent of total bases
Exchangeable K	0·3796 per cent of total bases
Exchangeable Na	0·3282 per cent of total bases

(*iv*)

Hygroscopic moisture (on fresh basis) . 5·9675 per cent

(*v*) Box constants

Apparent density	1·398 gm. per c.c.
Water holding capacity	46·71 per cent.
Specific gravity	2·231
Pore space	55·30 c.c. per 100 c.c.
Volume expansion	33·53 c.c. per 100 c.c.
Conductivity	$186 \cdot 7 \times 10^{-6}$ r. o.
Total soluble salts (weight)	0·047 per cent

(*vi*) Mechanical analysis

(*a*) By Bouyoucos' method	(1·00-0·05)	(0·05-0·005)	(0·005-0·002)	<0·002
Aggregate (water dispersed) . . .	74·2	21·4	2·4	2·0
Ultimate (mechanically dispersed) . .	9·9	35·7	6·7	47·7
		(0·5-0·05)	(0·05-0·005)	<0·005
(*b*) Pipette method (Puri's Nacl Dispersion method) . . .		25·5	20·0	53·8

(*c*) Structure coefficient— $\frac{D—S}{D} = 0 \cdot 7137$

The results of the periodical examination (expressed on oven-dried basis) are given in Table III. These are the averages of four determinations. They have been statistically examined by Fisher's analysis of variance and standard error for the results and their (marginal) averages, are also given.*

TABLE III

Nitrate nitrogen mg. per 100 gm. soil

(Average results)

	Average time						Standard error
	Initial	32 days	60 days	94 days	123 days	Average	
Control	2·58	2·06	2·97	6·22	5·21	3·81	±0·3448
25 lb. N	5·25	4·05	5·20	8·48	8·71	6·34	
50 lb. N	7·59	10·94	7·77	10·27	10·06	9·32	
Standard error = ±0·7712							
Average	5·14	5·68	5·32	8·32	7·99		

Standard error = ±0·4453

It will be seen from the above analysis that the untreated soil and that treated with 25 lb. of nitrogen do not show any increase in the nitrate nitrogen up to 60 days, and the rise after this period remains practically constant. But with 50 lb. the nitrate nitrogen increases in the first four weeks and then falls during the next month; it again rises after eight weeks and remains steady.

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[*] For convenience of presentation the data in the tables are given only up to two places of decimal although in the statistical computation figures up to four places of decimal were used.

If the averages are considered, it is found that, on the whole, in all the three cases, the nitrate nitrogen remains steady up to 60 days ; it reaches its highest value after 94 days and remains steady in the following month. The sudden increase in the 50 lb. N treatment after 32 days can be explained as an interaction.

During all the five stages there is, on the whole, a tendency for an increase in the nitrification in 25 lb. N treatment which is greater than the control, while that treated with the double dose is significantly greater than the one with the single dose. It will also be seen that the single dose shows a higher production of nitrate nitrogen than the control at all stages excepting the second. The 50 lb. application produces significantly more nitrates than the 25 lb. one, up to 8 weeks only, although its nitrate contents are higher than the control in the last two stages. It will be noted that the nitrate nitrogen obtained by analysis is greater than the added N, which is about 2 mg. in the case of 25 lb. N and 4 mg. in the case of 50 lb. N per 100 grams of the soil. This shows that in addition to the nitrogen added, the soil nitrogen also undergoes nitrification. Similar observations have been made by Yuen and Boden [1937] who found that the rate of nitrification is variable and the process does not necessarily occur like a quantitative reaction, the increase in the nitrate nitrogen being sometimes greater than the equivalent of nitrogen added.

TABLE IV

Ammoniacal nitrogen mg. per 100 gm. soil

(Average results)

	Average time						
	Initial	32 days	60 days	94 days	123 days	Average	
Control	7·37	4·24	3·39	2·54	4·34	4·35	Standard error ±0·29
25 lb. N	6·57	3·85	2·64	3·00	4·34	4·03	
50 lb. N	5·39	3·77	3·06	3·54	4·10	3·97	
Standard error = ±0·62							
Average	6·44	3·95	2·94	2·99	4·26		

Standard error = ±0·38

It will be seen from Table IV that in the treated soils and the control the ammoniacal nitrogen starts decreasing during the first 60 days. In the control and the 25 lb. N treatment it has already decreased significantly in the first 32 days, whereas in the case of 50 lb. N treatment it slowly decreases till this decrease reaches its significance in 60 days. Thus, it can be concluded that the nitrification is rapid in the control and the 25 lb. N treatment. The ammoniacal nitrogen content remains constant later on in the two treated samples but the control shows a slightly significant increase after 94 days.

If these results are examined together it can be seen that there is an abundance of ammoniacal nitrogen in the initial stages but it decreases in the next four weeks. Then it remains steady for 94 days and afterwards shows an increase. But it will be seen that the ammonia contents of both the treated and the untreated soil are small at all stages.

It will be further seen that there is not much difference in the ammoniacal nitrogen content due to the differences in the treatment. Only in the initial stage the control shows a significant increase over the 50 lb. N treatment. At other stages there are no significant differences. This can also be seen to be true from the averages of the results.

Table V

Organic carbon mg. per 100 gm. soil

(Average results)

—	Average time						
	Initial	32 days	60 days	94 days	123 days	Average	
Control	412·8	512·1	633·1	577·8	564·1	541·9	**Standard error ±12·45**
25 lb. N.	342·8	553·5	627·4	617·7	522·9	532·8	
50 lb. N.	482·7	582·2	640·3	591·5	491·8	557·7	
Standard error = ±26·91							
Average	412·8	549·2	633·6	598·9	526·2		
Standard error = ±16·09							

In all cases the organic carbon increases in the first 32 days ; in the next 28 days there is a significant increase over the last stage in the case of the control only. In the next 34 days the carbon contents are steady in all the three cases. But during the last 30 days although the carbon content in the control and 25 lb. N treatment remains steady, with slight fluctuation, it decreases significantly in the double treatment.

In general, it will be seen that there is a tendency for the carbon content to increase in all the three cases during the first 60 days of the experiment. Later on it remains steady for the next 34 days.

There are no differences in the carbon content due to the differences in the treatment in all the five stages. However, it will be noted that, in the initial stage, there is some difference (not significant) in the three cases. The general average also shows a fair constancy of the carbon content in the different treatments.

It can be seen from Table VI that in the case of control, the ratio is steady in the beginning, increases in the next 28 days and remains steady later on. However, in the case of the 25 lb. N treated samples the increase is significant in the first 32 days and in the next 28 days, whereas in the 50 lb. N treatment there is a significant increase only in the first 32 days. Later on, the ratio in the two treated sampels remains constant with insignificant variations, although a tendency for decrease is seen.

TABLE VI

C/N ratio

(Average results)

—	Average time						Standard error
	Initial	32 days	60 days	94 days	123 days	Average	
Control	4·82	5·33	6·54	6·28	6·75	5·96	
25 lb. N.	3·57	5·98	7·21	6·56	5·94	5·77	±0·17
50 lb. N.	5·29	6·45	6·38	6·16	5·61	5·99	

Standard error = ±0·37

Average	4·66	5·79	6·71	6·36	6·03

Standard error = ±0·22

The results as a whole show that the ratio increases during the first 60 days, remains steady during the next 34 days, and starts decreasing later on.

No changes take place (in the initial and the subsequent stages) due to different treatments. In the initial stage the ratio in the case of 50 lb. N treatment and the control is greater than the 25 lb. N treatment. This is in accord with the organic carbon content in the corresponding stage. In the next stage, however, the ratio in the 50 lb. N treatment is significantly greater than the control. The general results show no significant increase or decrease in the ratio due to the different treatments. Since the C/N ratio shows similar variations as carbon it may be inferred that there may not be any changes in the actual nitrogen content of the soil during the experimental period. Russell has shown that this nitrogen cannot increase by itself; and increase is possible only when some carbonaceous matter is added along with the nitrifying agent to the soil. The gain in nitrogen, under these circumstances, is only 1/10 of that of the carbon. Only nitrogeneous fertilizers such as $(NH_4)_2SO_4$ do not add any nitrogen to the soil beyond that which corresponds to the carbon added, if any, to the soil by the stubble.

TABLE VII

Hygroscopic moisture per 100 gm. soil

(Average results)

—	Average time						Standard error
	Initial	32 days	60 days	94 days	123 days	Average	
Control	5·53	6·26	8·02	6·85	6·23	6·58	
25 lb. N.	5·64	6·46	8·01	6·86	6·24	6·64	±0·03
50 lb. N.	5·47	6·37	8·08	6·86	6·31	6·62	

Standard error = ±0·07

Average	5·55	6·36	8·04	6·86	6·26

Standard error = ±0·043

The changes in the hygroscopic moisture in the different stages are highly significant. It can be seen that in all the three cases the hygroscopic moisture increases in the first 60 days, reaches a maximum value and then decreases. The values reached at the end of 123 days are nearly the same as those after 32 days. Hence it may be concluded that the decrease in the available water during the first two months is comparatively more rapid than its increase during the next two months. Assuming that the hygroscopic moisture is proportional to colloid content the marked increase in the latter at the end of the eighth week perhaps causes a lack of aeration which leads to the formation of an algal film which was observed in all cases [Wad and Panse, 1933].

During all the stages it is found that there are no significant differences in the hygroscopic moisture, and hence, in the colloidal content due to the addition of manure. However, it may be mentioned that on the whole the colloid contents are numerically higher in the case of the 25 lb. N treatment than 50 lb. N treatment, which is in turn higher than the control, although these differences are insignificant.

TABLE VIII

Available P_2O_5 mg. per 100 gm. soil

(Average results)

	Average time				
	Initial	60 days	123 days	Average	
Control	13·69	13·03	10·24	12·30	Standard error ±0·43
25 lb. N	11·49	14·81	10·35	12·24	
50 lb. N	13·78	15·51	12·02	13·77	

Standard error = ±0·74

Average	13·01	14·45	10·85	

Standard error = ±0·43

It will be seen that the available P_2O_5 content in the case of the control and the 50 lb. N treatment remains steady in the first 60 days although there is a tendency to increase in the latter case (not a significant one). But in the case of the 25 lb. N treatment there is a more significant increase in this period. In the next 60 days the available P_2O_5 content significantly decreases in all the three treatments and the contents on the 123rd day are less than in the initial stage. The average results show that the P_2O_5 content increases in the first 60 days and decreases evenly during the subsequent two months.

It will also be seen that in the initial stage the 50 lb. N treatment and the control contain the same amount of available P_2O_5 and this is significantly greater than the value for the 25 lb. N treatment. But after 60 days the 50 lb. N treated samples have significantly more P_2O_5 than the control, the 25 lb. N treatment being midway, though the differences are insignificant. In the next 63 days the 25 lb. N and the control have practically the same available P_2O_5 whereas 50 lb. N treatment has more. This is also clear from the average results which show that the 50 lb. N treatment is significantly superior to the control and the 25 lb. N treatment as regards the available P_2O_5 contents.

TABLE IX

Base exchange capacity (m.e/100 gm. soil)

(Average results)

—	Average time				
	Initial	60 days	123 days	Average	
Control	56·20	57·21	55·61	56·34	Standard error ±0·24
25 lb. N.	56·47	57·48	56·11	56·69	
50 lb. N	55·76	57·57	55·92	56·41	

Standard error= ±0·42

Average	56·14	57·42	55·88

Standard error= ±0·24

The base exchange capacity increases in the first 60 days only in the case of the soil treated with 50 lb. N. In the other two cases the increase is not significant though there is a slight rise. But in the following 63 days the exchange capacity decreases significantly in all the cases. The average results show that the exchange capacity increases in the first two months and decreases in the next two, attaining the original level once again. Thus it may be surmised that in the case of the control and 25 lb. N treatment the maximum exchange capacity might have been attained sometime between 40 and 80 days from the start.

There are no differences in the exchange capacity at any stage due to the differences in the treatment. In general the control as also the treated soils behaves similarly as regards the exchange capacity.

TABLE X

Total exchangeable bases (m. e. per 100 gm. soil)

(Average results)

—	Average time				
	Initial	60 days	123 days	Average	
Control	56·17	63·68	59·58	59·81	Standard error ±0·33
25 lb. N	59·77	61·30	60·91	60·65	
50 lb. N	59·24	60·87	60·78	60·29	
Standard error = ±0·57					
Average	58·39	61·95	60·42		
Standard error = ±0·33					

The total exchangeable bases in the control increase during the first 60 days but in the case of the treated samples the increase is not significant though there is undoubtedly a tendency to increase. It may be that the interaction in this case is rapid and the maximum was reached before 60 days, that is earlier than in the case of the control. In the next two months the treated samples show a decrease which is very marked in the case of the control. Further, the average results show that the total exchangeable bases increase in amount during the first 60 days and decrease in the next 60 days. The amount of the bases on the 123rd day is greater than that at the start in all cases (distinctly significant in the case of control only).

The results for the treatments present a very interesting example of interaction, for in the initial stage both the 25 lb. and 50 lb. N treated samples have a markedly higher base content than the control but after 60 days the total base content of the control is greater than that of the treated samples. In the last stage, however, these values are almost identical irrespective of the treatments. It is observed that the value for the total exchangeable bases are generally higher than the base exchange capacity of corresponding soil sample. It must be pointed out in this connection that the individual replaceable bases were determined on the soil samples not freed from soluble salts either by electrodialysis or by leaching with water. It is therefore possible that the differences might be due to this cause, but in view of the somewhat large differences observed (up to 11 per cent), there might be other unknown factors for the discrepancies.

It is seen that in all the three cases the exchangeable calcium increases in the first 60 days and then remains almost steady. Same conclusion can be drawn from the average results. The treatments amongst themselves show a peculiar behaviour for at the initial stage the exchangeable calcium of the 25 lb. and 50 lb. N treatments is significantly greater than that of the control but in the subsequent stages it has almost the same value in all three cases. In general it can be seen that the soil receiving the double treatment is definitely richer in exchangeable calcium than the control. That receiving the single treatment behaves almost similarly as the other treated soil. No determinations were made of soluble calcium, *p*H, and bicarbonate at the different stages. In the absence of these data, therefore, it is difficult to interpret the changes in the exchangeable calcium resulting from the treatments, for the calcium analytically determined need not necessarily be present in the exchangeable form.

TABLE XI

Exchangeable calcium (m. e. per 100 gm. soil)

(Average results)

	Average time				
	Initial	60 days	123 days	Average	
Control	91·17	93·90	94·11	93·06	Standard error ±0·20
25 lb. N	92·29	94·23	94·46	93·66	
50 lb. N	92·95	94·12	94·43	93·83	
Standard error= ±0·35					
Average	92·14	94·08	94·33		

Standard error= ±0·20.

TABLE XII

Exchangeable magnesium (m. e. per 100 gm. soil)

(Average results)

	Average time				
	Initial	60 days	123 days	Average	
Control	7·79	5·29	5·33	6·14	Standard error ±0·19
25 lb. N	7·10	5·11	5·14	5·78	
50 lb. N	6·42	5·45	5·21	5·69	
Standard error= ±0·33					
Average	7·1076	5·288	5·22		

Standard error= ±0·19

With the control and the 25 lb. N treatment there is a significant decrease in the exchangeable magnesium during the first 60 days whereas in the case of the 50 lb. N treatment the decrease is not very significant. The exchangeable magnesium remains fairly steady during the next 63 days in all three cases.

It will also be seen that there are no significant differences in the content of exchangeable magnesium in the different stages owing to the differences in the treatment, except in the initial stage where the exchangeable magnesium of the control is significantly greater than that of the treatments, specially, the double treatment. This may be due to the fact that the magnesium in the two latter cases does not exist in the exchangeable form. It is also probable that the exchangeable magnesium contents of the 50 lb. N treatment are not correctly determined, for no differences are noticed due to the differences in the treatment in the average results.

TABLE XIII

Exchangeable potassium (m. e. per 100 gm. soil)

(Average results)

	Average time				
	Initial	60 days	123 days	Average	
Control	0·76	0·57	0·40	0·58	Standard error ± 0·03
25 lb. N	0·40	0·45	0·28	0·38	
50 lb. N	0·32	0·23	0·20	0·27	

Standard error = ±0·05

Average	0·5202	0·4203	0·29

Standard error = ±0·03

The treated and the untreated soils behave differently with respect to the exchangeable potassium content. While in the case of the control the exchangeable potassium shows a continual decrease, there is no significant change in the treated samples. However, in the 25 lb. N treated soil there is an indication of the approach of a significant decrease during the last 63 days. The average results, however, show a significant decrease with time.

Differences in the exchangeable potassium due to the differences in the treatment are significant in the initial stage. The potassium contents in both the 25 lb. N and 50 lb. N treatments are significantly less than that in the control. At the next two stages the exchangeable potassium significantly decreases in the 50 lb. N treatment as compared with the control but no significant change is noted in the 25 lb. N treated soil. But the average results show that the significant effect of treatment is to cause a decrease in the potassium content.

In this case the blocks are also significant which shows that the random distribution of the trays has taken part in bringing about the above changes.

TABLE XIV

Exchangeable sodium (m. e. per 100 gm. soil)

(Average results)

—	Average time				
	Initial	60 days	123 days	Average	
Control	0·24	0·21	0·14	0·20	Standard error ±0·008
25 lb. N	0·18	0·19	0·12	0·17	
50 lb. N	0·21	0·20	0·15	0·19	
Standard error= ±0·015					
Average	0·21	0·20	0·14		

Standard error= ±0·008

All the three sets of soils behave similarly. In the first 60 days the exchangeable sodium remains constant and there is a significant decrease in the next 63 days.

There are no significant differences due to the differences in the treatment. Only at the first stage of the control the exchangeable sodium is significantly greater than that of the 25 lb. N treated soil. In the other two stages it has the same value for all three sets of soil.

In all three cases there are no changes in the structure coefficient which determines the soil fertility at any period.

CONCLUSIONS AND SUMMARY

The results of the present investigation show that many of the improvements in the soil properties take place during the first two months after the treatment. Thus, the amount of nitrate which is supposed to have an adverse effect on soil is least in this period and increases only after three months from the start. The ammoniacal nitrogen is in equilibrium with the nitrate nitrogen during this period. The organic carbon also increases during the first two months as a result of the formation of algae. Afterwards it starts decreasing ; this decrease may be due to an increase in the nitrifying activities probably at the cost of the algae.

TABLE XV

Structure coefficient

(Average results)

	Average time				
—	Initial	60 days	123 days	Average	
Control	0·76	0·78	0·76	0·77	Standard error ±0·006
25 lb. N	0·80	0·77	0·80	0·79	
50 lb. N	0·75	0·80	0·78	0·77	

Standard error= ±0·01

Average	0·77	0·78	0·78	

Standard error= ±0·006

The C/N ratio remains fairly steady throughout the experiment, though there is an increase in the fertility of the soil. The available P_2O_5 content does not seem to have any correlation with the nitrate nitrogen.

The base exchange capacity, the total exchangeable bases and the exchangeable calcium increase in the first two months and there is a decrease in the next two months. This fact indicates the necessity of determining, correlations, if any, existing between these quantities and opens a new line for such work. Replaceable sodium and potassium decrease both with the treatment and time while exchangeable magnesium decreases only with time and not with the treatment.

The hygroscopic moisture increases in the first two months which shows that the colloidal matter of the soil increases during this period. But the treatment with ammonium sulphate does not show any changes in the clay content of the soil. Also the structure coefficients at various periods during the experiment do not show any changes even at the higher rates of treatment. This shows that the application of ammonium sulphate causes no deterioration in the soil structure of a permanent nature as far as the crop-season is concerned.

In conclusion it may be said that the application of ammonium sulphate in doses used in this experiment increases the soil fertility and productivity. This important conclusion is in conformity with the observation (Annual Reports I. P. I.), that the black cotton soil yields better crop when small doses of ammonium sulphate (e.g. as used in this investigation) are added. In the two doses given in this work the soil properties are altered only in the first two months of experiment. This period of two months is the usual duration for the vigorous growth of a plant. The results point to the utility of the application of the fertilizer in the appropriate dosage to cause maximum beneficial effects during the period.

REFERENCES

Annual Reports, Institute of Plant Industry, Indore, C. I.
Bouyoucos, G. J. (1934). *Soil Sci.* **38,** 335
Plymen, F. J. and Bal, D. V. (1925). *Mem. Dept. Agric. India Chem.*
Puri, A. N. (1935). *Soil Sci.* **40,** 159, 249
—— —— (1936). *Soil Sci.* **42,** 47
Russell, E. J. (1938). *Tech. Com. Imp. Bur. Soil Sci.* No. **37**
Wad, Y. D. and Aurangabadkar (1936). *Indian J. agric. Sci.* **6,** 136
—— —— —— —— (1937). *Proc. Nat. Inst. Sci., India* **2,** 371
Wad, Y. D. and Ghosh (1938). *Proc. Soc. Biol. Chem.* (*India*) **1,** 1
Wad, Y. D. and Panse, V. G. (1933). *Indian J. agric. Sci.* **3,** 820
Yuen and Boden (1937). *Hawaiin Planters' Rec.* **41,** 353

RESPIRATION STUDIES OF THE ALPHONSO MANGO

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(With Plate LXIX and two text-figures)

DURING the course of the cold storage investigations on mangoes [Cheema, Karmarkar and Joshi, 1939] it was observed that the Alphonso mango of ' B ' stage of maturity (green and mature) was the best keeper. The most suitable range of temperature for storing the fruit was between 45° and 48°F. and the fruit ripened satisfactorily afterwards when removed to 68°F. Ripe yellow fruit (eating maturity) became chilled and turned brown at 52° F. and lower temperatures. Green fruit became chilled at temperatures lower than 45°F. and did not ripen properly when subsequently exposed to a higher temperature. Further experiments on the chilling of ripe Alphonso mango fruit showed that the browning occurring in storage at 52°F. could be prevented by keeping the fruit under partial vacuum. The respiratory activity is closely connected with the metabolic processes and it appeared that a study of the changes in the rate of respiration would throw light upon the nature of the physiological changes taking place in the fruit in storage. Experiments, therefore, were undertaken to determine the rate of respiration of the Alphonso mango under different storage conditions.

EXPERIMENTAL METHOD

The intensity of respiration was measured by the amount of carbon dioxide produced by the fruit sample kept in a closed container. A wide mouthed (4 in. diameter) glass jar of about 2500 c.c. capacity was used as the respiration chamber (Plate LXIX). The jar was closed by means of a tight-fitting rubber cork. A separating funnel and a bent glass tube were fitted into the cork. To the lower end of the funnel tube was attached a piece of rubber tubing reaching the bottom of the jar. Another piece of rubber tubing, provided with a pinch-cock, was attached to the outer end of the bent glass tube so that it could be connected either to a manometer during the respiration experiment or when required, to the inlet tube of the gas analysis apparatus.

The fruit sample was placed on a wire gauze platform about two inches above the bottom of the jar in order that the fruits did not come in direct contact with the water run into the jar through the separating funnel for displacement of the gas sample for analysis. The gas analysis was made at 68°F. using the Orsat's gas analysis apparatus. The percentages of both carbon dioxide and oxygen were determined. The change in pressure occurring in the respiration jar was noted and the necessary correction was made in calculating the volumes of carbon dioxide and oxygen. The quantity of air available for respiration in the closed jar was the total volume of the jar minus the volume of the fruits. As the specific gravity of the mango is nearly unity, the volume of the fruits in c.c. was approximately equal to their weight in gm. The rate of respiration has been expressed as the volume in c.c. of carbon dioxide at 68°F. and 710 mm. (atmospheric) pressure, produced by 100 gm. of fruit in 24 hours.

The fruit used in these experiments was obtained from Ratnagiri and was in transit for two days. The temperature of the cold rooms in which the rate of respiration was determined showed a variation of ± 1°F.

RESULTS

THE COURSE OF RESPIRATION DURING RIPENING AT 68°F.

Five samples, each consisting of three fruits of 'B' stage of maturity, were used. Cheema and Dani [1934] have defined this stage of maturity as the condition of fruit during development on the tree when the shoulders outgrow the stem-end and the colour is oil-green. The period of the respiration experiment was four hours and, after the experiment, the fruits were removed from the jars and kept in open trays. The respiratory activity of these five samples was determined every day until they became ripe. The data obtained are shown in Table I and are also represented graphically in Fig. 1. The values obtained for the initial rate of respiration at 68°F. showed

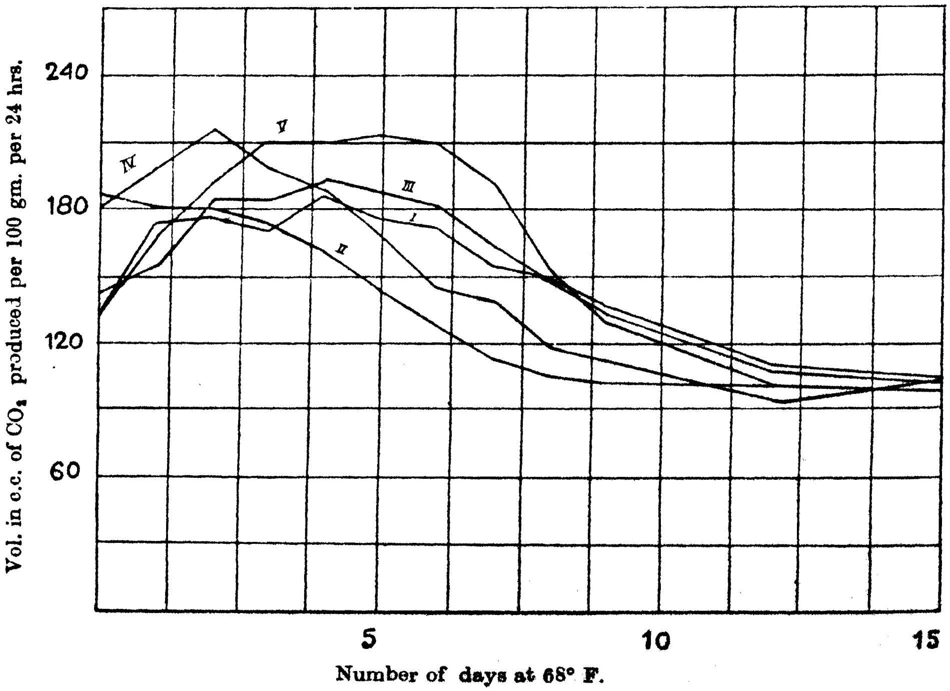
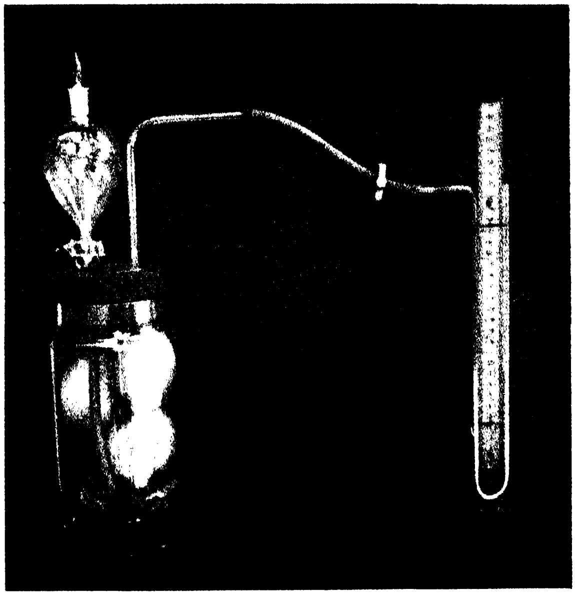


FIG. 1. The changes in the rate of respiration of green Alphonso fruit during ripening time at 68° F.



Apparatus used for the determination of respiratory activity

a considerable variation among individual samples, even though the fruits were apparently at an equal stage of maturity.

The results showed that, except in sample II, there was a rapid rise in the respiratory activity until the peak value or climacteric was reached. In samples I and III the peak value occurred on the fourth day, while in samples IV and V it occurred after two and five days respectively. It would appear that the fruits of sample II had already reached the climacteric when they were placed in storage at 68°F. Leley [1938], working with Alphonso mango fruit, observed that the climacteric rise began two days after picking. As the fruits used in these respiration experiments were of ' B ' stage of maturity, i.e. the condition previously found most suitable for cold storage, it may be concluded that this stage of maturity takes place in the pre-climacteric phase of the life-cycle of the fruit. The variation in respiratory activity among individual samples at the beginning of the experiments might, therefore, be due to the difference in their stage of the climacteric rise.

It was observed by Banerjee, Karmarkar and Rao [1934], in their experiments with the Neelam variety of mango, that the rate of respiration was closely connected with the process of ripening. Leley [1938], working with the Alphonso mango, and Singh, Sheshagiri and Gupta [1937,1], working with the Krishnabhog and Langra varieties of mango, observed that there was a climacteric rise with the commencement of ripening. In these experiments, the maximum value of the rate of respiration occurred when the fruits were still hard and green or were just beginning to change colour. The fruits gradually turned yellow, became soft and were fully ripe after nine days. During this latter period of ripening, the rate of respiration decreased until it was approximately 100 c.c. of carbon dioxide in all the samples. Thereafter, the rate remained steady until the fruits became over-ripe. Leley [1938] noticed that the fruits had the best eating quality when the rate of respiration was at its lowest.

The nature of the substrate for respiration

The peak value of the respiratory intensity was observed when the fruits were still green in appearance and were very sour. Cheema, Karmarkar and Joshi [1939] found that, in green Alphonso mango fruit, the amount of total sugars was comparatively small, approximately 2·5 per cent, but that it increased during the process of ripening and reached nearly 13 per cent in the ripe fruit. The decrease in the rate of respiration was thus accompanied by an increase in the amount of total sugars. It may be inferred, therefore, that the rate of respiration was not influenced by the percentage of total sugars and that the decrease in the rate was due to the depletion of some other constituent, probably the acids present in the fruit.

Cheema, Karmarkar and Joshi [1939] noted that the acidity of the Alphonso mango was considerably reduced during ripening. It decreased from about 2·5 per cent in green fruit to about 0·2 per cent in the ripe fruit. The percentage of acidity was determined at different stages of ripening at 68°F. and the values obtained are given in Table II. The acidity of the fruit ripened at 68°F. after cold storage was also determined.

TABLE I

Changes in the respiratory activity during ripening at 68°F.

Number of days at 68°F.	Stage of ripening	Sample I		Sample II		Sample III		Sample IV		Sample V	
		CO_2 per 100 gm. per 24 hours c.c.	Respiratory quotient	CO_2 per 100 gm. per 24 hours c.c.	Respiratory quotient	CO_2 per 100 gm. per 24 hours c.c.	Respiratory quotient	CO_2 per 100 gm. per 24 hours c.c.	Respiratory quotient	CO_2 per 100 gm. per 24 hours c. c.	Respiratory quotient
0	...	134	1·084	186	1·069	142	1·012	179	1·076	134	1·067
1	Green and	175	1·097	180	1·032	153	1·058	198	1·075	167	1·042
2	hard	177	1·120	181	1·069	183	1·105	215	1·096	191	1·089
3	Slightly	172	1·108	173	1·098	184	1·110	197	1·073	210	1·126
4	changing	187	1·156	163	1·113	192	1·104	190	1·166	210	1·104
5	colour	176	1·193	143	1·086	187	1·160	167	1·137	213	1·179
6	...	175	1·199	130	1·024	181	1·134	148	1·127	209	1·185
7	Turning	157	1·164	114	0·944	161	1·130	141	1·066	192	1·172
8	Yellow	150	1·126	105	0·913	147	1·103	119	1·018	154	1·111
9	...	139	1·076	103	0·879	131	1·010	113	0·985	128	1·047
12	Ripe	111	0·914	102	0·841	104	0·866	97	0·856	102	0·902
15	Yellow	106	0·840	96	0·808	103	0·882	106	0·898	...	...
24	Over-ripe	...	...	...	...	100	0·825	101	0·767	101	0·845

TABLE II

Changes in acidity during ripening at 68°F.

Stage of ripening	Percentage of acidity in terms of malic acid on fresh weight basis
Green and hard	2·15
Slight change of colour	1·50
Turning yellow	0·29
Yellow	0·19
Fully ripe	0·18
Over-ripe	0·16
Ripened at 68°F. after storage for 30 days at 45°F. (fully ripe)	0·89
Ripened at 68°F. after storage for 40 days at 45°F. (fully ripe)	0·80

The percentage of acids thus decreased with the rate of respiration. The respiratory quotient (Table I) was only slightly greater than unity in the beginning, but it increased appreciably when the fruits commenced to turn yellow. This increase in the values of the respiratory quotient indicated that a part of the substrate for respiration consisted of the acids which became depleted during ripening. The value of the respiratory quotient decreased when the fruits were ripe and in the end became less than unity. Singh, Sheshagiri and Gupta [1937, 2] obtained values of the respiratory quotient which were less than unity and inferred that the nature of the respiration substrate in mangoes was a mixture of fats and carbohydrates. Wardlaw and Leonard [1940] have, however, shown the importance of the internal concentrations of carbon dioxide and oxygen in the fruit in studying the changes in the rate of respiration as determined by the amounts of carbon dioxide liberated at the surface and oxygen consumed.

RELATION OF THE RESPIRATORY QUOTIENT TO THE FRESHNESS OF FRUIT

The fruit used in the above experiments was obtained from Ratnagiri and was in transit for two days from that place to the Experimental Station at Ganeshkhind, Poona. The data given in Table I show that there was a rapid rise in the rate of respiration when the samples were kept at 68°F. It can be assumed that the rate of respiration was much lower at the time of picking. Fresh Alphonso fruit of 'B' stage of maturity was also obtained locally and the rate of respiration and the respiratory quotient were determined at 68°F. It was observed that not only was the rate of respiration very low (values between 40 c.c. and 80 c.c. were obtained) but the respiratory quotient of the local fresh fruit was less than unity (0·8 to 0·9) in all the samples. On storing the fruit at 68°F., the rate of respiration increased in two days and the respiratory quotient became greater than unity.

The less-than-unity values of the respiratory quotient indicate that a relatively larger volume of oxygen was consumed in the process of respiration than the volume of carbon dioxide produced. The manometer attached to the respiration jar consequently showed a depression in pressure. The respiratory quotient of the fruit kept for two days at 68°F. became greater than unity and the manometer showed a small increase in pressure. The depression in the pressure of the respiration jar could, therefore, be employed as a test of the degree of freshness of fruit. The respiration process has been utilized by Harvey and Rygg [1936] to indicate the vitality of citrus fruit in relation to its keeping quality.

RRELATION OF TEMPERATURE TO THE RATE OF RESPIRATION

Determinations of the rate of respiration were made at temperatures of 68°, 52°, 48°, 40° and 35°F. Two samples of green fruit were obtained and the same samples were used for determining the rate of respiration at the above temperatures. As mentioned above there was a considerable variation among individual samples and it was thought that using the same samples at different temperatures would give more reliable data than using separate samples at each temperature. First the rate was determined at 68°F. and then the samples were removed to 52°F. and the other temperatures. At each temperature, the samples were kept for a day so that the fruits attained the temperature of the storage chamber. The results given in Table III showed that the rate of respiration decreased with temperature. There was, however, a marked decrease between 52° and 48°F.

TABLE III

The rate of respiration at different temperatures

Temperature	Volume of carbon dioxide in c.c. per 100 gm. per 24 hours	
	Sample I	Sample II
68°F.	142	173
52° F.	78	92
48°F.	43	47
40°F.	22	26
35°F.	17	20

RESPIRATION DURING STORAGE AT 48°F. AND AFTER REMOVAL TO 68°F.

The rates of respiration of three samples of 'B' stage fruit were first determined at 68°F. after which the samples were removed and kept at a storage temperature of 48°F. The rate was again determined at intervals during storage at 48°F. One of the samples was removed to 68°F. after thirty-five days of storage at 48°F. and another after forty-one days. The rates of respiration of these two samples were then determined at 68°F. at different stages of ripening. The data are given in Table IV.

The data show that; under storage at 48°F., the rate of respiration declined in the first fortnight, but afterwards remained steady up to the end of the storage period. The rates of respiration at 68°F. of green fruit removed from 48°F., after storage for thirty-five and forty-one days at that temperature (samples II and III), were lower than the initial rates of fresh fruit stored at that temperature, i.e. 68°F. It was noted that the rate of respiration did not decrease during ripening of the cold-stored fruit as in the case of fresh fruit ripened at 68°F. (Table I). The percentage of acidity (Table II) in the fully ripe fruit ripened after cold storage also remained higher than that in the fresh fruit ripened at 68°F.

THE EFFECT OF CHILLING ON RESPIRATION

The green Alphonso mango is chilled at temperatures lower than 45°F. and the fruit fails to ripen when subsequently removed to higher temperatures. It has also been observed that ripe yellow fruit is chilled at 52°F. and lower temperatures and the typical bright yellow colour turns brown. Two samples of green fruit were kept at 35°F. and three samples of ripe fruit at 52°F. The rates of respiration of these samples were determined at intervals. The results are given in Table V. It can be observed that chilling did not appear to have any marked effect on the rate of respiration. At 52°F. the rate showed an increase after two weeks when the fruit became dark brown and rotting commenced.

TABLE IV

The rate of respiration during storage at 48°F. and after removal to 68°F.

	Volume in c.c. of carbon dioxide per 100 gm. per 24 hours		
	Sample I	Sample II	Sample III
Initial at 68°F.	252	218	194
	Stored at 48°F.		
Number of days of storage at 48°F.—			
3	64	58	56
8	47	49	47
14	39	42	39
20	36	40	37
25	38	40	38
30	37	39	37
35	..	39	41
		Removed to 68°F.	
41	..	..	39
			Removed to 68°F.
	Ripened at 68° F. after cold storage		
Number of days after removal to 68°F.—	Stage of ripening		
2	Green	195	164
6	Changing colour	176	172
9	Yellow	160	165
13	Fully ripe	171	159
17	..	170	..

TABLE V

The effect of chilling injury on the rate of respiration

35°F.			52°F.			
Number of days of storage	Volume in c.c. of carbon dioxide per 100 gm. per 24 hours		Number of days of storage	Volume in c.c. of carbon dioxide per 100 gm. per 24 hours		
	Sample I	Sample II		Sample I	Sample II	Sample III
0	20	17	0	79	79	73
8	20	20	2	67	70	69
18	23	20	4	66	76	74
			6	58	65	66
			9	65	72	68
			15	63	81	80
			22	73	85	86

RESPIRATION UNDER PARTIAL VACUUM

In their studies on the chilling of mangoes, the authors observed that the browning of ripe yellow fruit was prevented by storage under partial vacuum under which conditions the colour remained unaffected for a month at 52°F. The effect of partial vacuum on the rate of respiration was, therefore, investigated. The amounts of carbon dioxide produced by two samples of green fruit in four hours at 68°F. were first determined. The samples were then removed from the respiration jars and kept in a vacuum of 640 mm. of mercury and then put back into the respiration jars. The amounts of carbon dioxide produced by the samples in an equal period at 68°F. were again determined. Before vacuum, the percentages of carbon dioxide produced in the two jars were 5·0 and 7·2 and after vacuum the percentages of carbon dioxide were 5·4 and 7·6 respectively. It may, therefore, be assumed that subjecting the fruit to partial vacuum for a short time did not produce any effect on the rate of respiration.

The respiratory activity of fruit kept continuously under partial vacuum at 68°F. was also determined. The sample was kept in a vacuum desiccator which served as the respiration chamber. The percentage of carbon dioxide produced in the desiccator in three hours under ordinary pressure was determined. The air in the desiccator was then changed and fresh air was admitted. The desiccator was then evacuated up to a vacuum of 240 mm. of mercury (approximately one third atmosphere) and the respiration of the sample was allowed to proceed under the reduced pressure. At the end of three hours, the vacuum was released by allowing fresh air into the desiccator. The percentage of carbon dioxide produced in the desiccator was determined. Similarly, the percentage of carbon dioxide produced by the same sample in three hours under a vacuum of 480 mm. of mercury (approximately two thirds atmosphere) was determined. As all the three determinations were made in the same desiccator and for an equal period, the percentage of carbon dioxide produced in the desiccator indicated the intensity of respiration of the fruit. The results are given in Table VI.

TABLE VI

Respiratory activity under partial vacuum at 68°F.

	Percentage of carbon dioxide produced			
	Green fruit		Ripe fruit	
	Sample I	Sample II	Sample I	Sample II
Atmospheric pressure (710 mm.)	9·4	12·8	4·0	4·2
240 mm. vacuum . . .	10·8	13·2	..	..
480 mm. vacuum . . .	11·0	11·0	5·2	4·5

The results in Table VI show that respiratory activity did not decline under reduced pressure but on the other hand, the values obtained indicate that there was probably some increase. If it is assumed that the browning of the yellow skin of ripe fruit when stored at 52°F. is due to the breaking of the cells in the skin and the subsequent oxidation of the cell contents by exposure to the atmospheric oxygen, the prevention of the development of brown colour could only be explained by the reduced quantity of oxygen under conditions of partial vacuum.

EFFECT OF CARBON DIOXIDE CONCENTRATION ON RESPIRATION

In the experiments described above, the period of the respiration experiment was so arranged that the concentration of the accumulated carbon dioxide produced in respiration did not normally exceed 10 per cent. High concentrations of carbon dioxide are generally supposed to have a depressing effect on respiratory activity. The effect of different concentrations of carbon dioxide on the rate of respiration of the Alphonso mango was studied. Two samples of green fruit were used. The respiration was allowed to continue at 68°F. for 24 hours when a high concentration of carbon dioxide was obtained. At intervals during the experimental period the percentages of carbon dioxide accumulated in the respiration jars were determined. For each determination 100 c.c. of the gas were obtained by displacement by an equal quantity of water. A correction for the amount of carbon dioxide absorbed by water remaining in the respiration jar was made in calculating the total quantity of carbon dioxide produced by the fruit. The data obtained are given in Table VII.

The total volume of carbon dioxide produced at intervals during the experimental period (Table VIII) has been represented graphically in fig. 2.

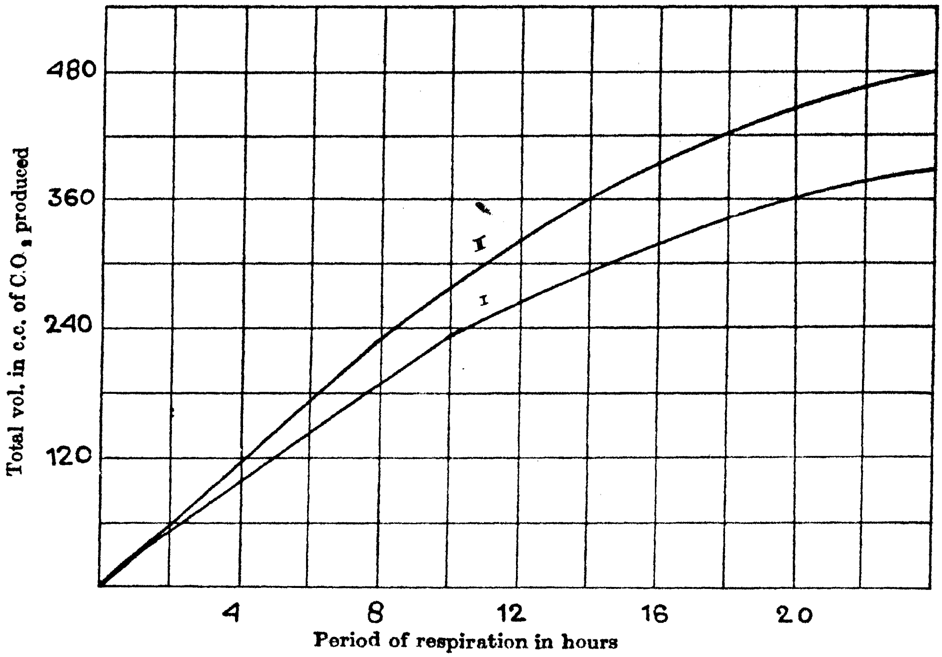


FIG. 2. The effect of increased concentrations of carbon dioxide on the respiratory activity of Alphonso mango

It will be observed from the figure that in sample I the rate of production of carbon dioxide was uniform up to 10 hours when the rate commenced to decline. The concentration of carbon dioxide at this point, i.e. after 10 hours, would have been approximately 11 per cent. In sample II, the rate was uniform up to eight hours when the concentration of carbon dioxide had reached 11 per cent. It can, therefore, be concluded that the accumulation of carbon dioxide in the respiration jar up to a concentration of about 11 per cent did not produce any depressing effect on the respiratory activity. In these experiments, the percentage of oxygen in the closed respiration jar was reduced corresponding to the increase in the carbon dioxide concentration, the respiratory quotient being about unity. The reduction in the percentage of oxygen from 21 per cent to 10 per cent did not, therefore, have any retarding action on respiratory activity. Indications of anaerobic respiration were not obtained even after an accumulation of 12·8 per cent of carbon dioxide in sample I and 15·4 per cent in sample II, i.e. after a reduction of oxygen percentages to 8·2 and 6·6 respectively. Definite anaerobic respiration occurred after 24 hours, i.e. after an accumulation of 19·2 per cent of carbon dioxide in sample I, and more than 21 per cent in sample II. Singh, Sheshagiri and Gupta [1937, 2] have noticed that an oxygen mixture of 9·2 per cent was the critical concentration below which there was probably competition between aerobiosis and anaerobiosis, the respiratory quotient at this critical point being 0·85.

RESPIRATION UNDER ANAEROBIC CONDITION

The respiration was allowed to continue at 68°F. until the concentration of carbon dioxide produced in the respiration jar was considerably more than 21 per cent, i.e. the percentage of oxygen in the air. It was observed that when all the oxygen was consumed and anaerobic respiration commenced, the manometer showed an increase of pressure. In a few samples, specially when the concentration of carbon dioxide produced was more than 30 per cent, the increase in pressure was not proportional to the anaerobic production of carbon dioxide but was much less. On calculation, it was found that in these cases there was a considerable decrease in the amounts of nitrogen (calculated by difference) in the respiration jar. The data appeared interesting and are recorded in Table VIII. No conclusion could be proposed as a result of these few stray observations until further corroborative data are obtained.

TABLE VII

The effect of the concentration of carbon dioxide on the rate of respiration

Period of respiration in hours	Sample I				Sample II			
	Percentage of CO_2 in the respiration jar	Total volume of CO_2 produced c.c.	Volume of CO_2 produced in the interval c.c.	Volume of oxygen consumed in the interval c.c.	Percentage of CO_2 in the respiration jar	Total volume of CO_2 produced c.c.	Volume of CO_2 produced in the interval c.c.	Volume of oxygen consumed in the interval c.c.
1	1·2	23	23	20	1·4	28	28	18
2	2·4	47	24	25	2·6	53	25	30
4	4·8	95	48	48	5·4	110	57	58
8	9·3	185	90	84	11·0	225	115	105
12	12·8	258	73	71	15·4	320	95	86
24	19·2	389	131	71	23·0	480	160	48

SUMMARY

1. In previous investigations on the cold storage of mango, it was found that the Alphonso mango was the best keeper in cold storage. The respiratory activity of this variety of fruit under different storage conditions has been studied.

2. The respiratory activity of green fruit ('B' stage of maturity) increased on keeping at 68°F., reached a peak value (climacteric) and then decreased during ripening. The 'B' stage of maturity—the condition found most suitable for cold storage—occurred in the pre-climacteric phase of the life-cycle of the fruit.

3. During ripening, the decline in the rate of respiration was accompanied by an increase in the amount of total sugars and a loss in acidity. It was inferred, therefore, that the rate of respiration was not influenced by the increase in the concentration of sugars and that it decreased due to the depletion of acids present in the fruit. The values of the respiratory quotient indicate that the acids formed a part of the respiration substrate.

TABLE VIII

Respiration under anaerobic condition

Period of respiration in hours	Volume of fruits c.c.	Original volume of air / oxygen (20·7 per cent) / nitrogen in the jar c.c.	Increase in pressure mm. of mercury	Volume of air in the jar at atmospheric pressure (710 mm.) c.c.	Percentage of CO_2 in the jar	Percentage of oxygen in the jar	Volume of CO_2 in the jar at 68°F. and 710 mm. pressure c.c.	Volume of oxygen in the jar at 68°F. and 710 mm. pressure c.c.	Volume of nitrogen in the jar at 68°F. and 710 mm. pressure (by difference) c.c.
43	605	2095 433 1662	64	2283	27·6	0·5	630	11	1642
26	578	2122 439 1683	93	2400	29·8	0·4	715	10	1675
43	539	2161 447 1714	104	2477	30·9	0·6	796	15	1666
26	498	2162 454 1708	103	2476	30·2	0·4	748	10	1718
24	452	2248 476 1772	63	2446	33·0	0·4	807	10	1629
24	498	2202 467 1735	66	2406	34·6	1·2	833	29	1544
26	664	1976 411 1565	15	2017	40·0	0·5	807	10	1210
48	539	2161 447 1714	54	2325	44·0	0·4	1023	9	1293
44	525	2175 461 1714	64	2371	46·0	2·0	1091	47	1233
45	500	2200 455 1745	73	2426	50·0	0·2	1213	5	1208

4. The respiratory quotient of fresh fruit of ' B ' stage of maturity was less than unity and the manometer attached to the respiration jar showed a decrease in pressure in the jar. The depression in pressure could be employed as a test for the freshness of the fruit.

5. The rate of respiration decreased with temperature. There was, however, a marked decrease between 52°F. and 48°F.

6. The rate of respiration declined in the first fortnight of storage at 48°F., but afterwards, it remained steady up to the end of the storage period (six weeks). The rate of respiration of fruit removed to 68°F. after storage at 48°F. did not decrease during ripening.

7. Chilling injury did not appear to have any marked effect on the rate of respiration.

8. The determinations of the respiratory activity of fruit kept under partial vacuum showed that the rate of respiration was not affected by the reduced pressure.

9. It was observed that the accumulation of carbon dioxide in the respiration jar up to a concentration of 11 per cent did not produce any depressing effect on the respiratory activity.

10. In a few samples, the increase in pressure in the respiration jar was not proportional to the anaerobic production of carbon dioxide. It was observed that there was a considerable decrease in the quantity of nitrogen in the respiration jar specially when the concentration of carbon dioxide produced was more than 30 per cent. No conclusion could be proposed as a result of these observations until further corroborative data are obtained.

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REFERENCES

Banerjee, B. N., Karmarkar, D. V. and Row, G. R. (1934). *Agric. Live-Stock, India* **4**, 36

Cheema, G. S. and Dani, P. G. (1934). *Dept. Agric. Bombay, Bull.* **170**

Cheema, G. S., Karmarkar, D. V. and Joshi, B. M. (1939). *Imp. Counc. agric. Res. (India), Misc. Bull.* **21**

Harvey, E. M. and Rygg, G. L. (1936). *Plant Physiol.* **11**, 647

Leley, V. K. (1938). *University of Bombay, M.Sc. thesis* (unpublished)

Singh, B. N., Sheshagiri, P. V. V. and Gupta, S. S. (1937, 1). *Indian J. agric. Sci.* **7**, 176

Singh, B. N., Sheshagiri, P. V. V. and Gupta, S. S. (1937, 2). *Ann. Bot. (N. S.)* **1**, 311

Wardlaw, C. W. and Leonard, E. R. (1940). *Ann. Bot. (N. S.)* **4**, 269

STUDIES ON THE FORMATION OF JELLIES FROM SOME INDIAN FRUITS

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INDIA possesses such wide range of climate and soil that there is no fruit of the temperate, the subtropical and the tropical regions that cannot be grown here, and many grow so abundantly that huge quantities go to waste every year. Yet India gets its supplies of fresh and preserved fruits in large quantities every year from foreign countries. The problem of utilization of this abundant supply of fruit, which is of such vital importance to the development of the fruit industry in this country, has unfortunately not received any great attention from chemists or industrialists. Although some systematic research on the preservation of fruits and vegetables in India has been in progress in the Fruit Products Laboratories, Lyallpur, yet the field of research in this line is so vast and the literature on Indian fruits so scanty, that the problem of making jellies from some Indian fruits was considered of sufficient importance by the present authors so as to deserve a careful and systematic study.

In the present investigation the optimum conditions of jelly formation from some Indian fruits have been made the subject of scientific study, involving a good deal of physico-chemical analyses of the fruits and the jellies with special reference to the relationships of sugar, acid and pectin most desirable for the formation of a highly statisfactory jelly. The industrial aspect of the problem has also received careful consideration and it is hoped that the data collected will serve a useful purpose.

According to Goldthwaite [1918], a fruit jelly is a beautiful coloured and transparent product of fruit juices, which is neither syrupy, gummy, sticky or tough, nor brittle, and it cuts easily with a spoon, leaving sparkling characteristic faces the angles of which retain their shape. Perhaps no better definition of the fruit jelly can be given.

The chemistry of jelly formation is chiefly concerned with pectin, acid and sugar concentrations. These three constituents form a rather definite equilibrium when jelly formation occurs. Time of cooking, temperature, salt concentration and the like are also important considerations, but their importance rests more particularly upon the manner in which they affect the pectin, acid and sugar constituents.

PECTIN

According to Meyers and Baker [1934] pectin in the unhydrolysed condition is mono-arabino-mono-galacto-diacetylheptamethoxyl-octagalacturonic acid. Nucleus of the pectin molecule is octa-galacturonic acid most likely formed by the union of two molecules of tetra-galacturonic acid with the elimination of one molecule of water. Tetra acid is most likely formed into a ring compound by the combination of four molecules of galacturonic acid with the elimination of four molecules of water. Seven of the eight carboxyl groups of the octa-galacturonic acid are methylated, and the other one is free. On this basis the empirical formula for pectin would be $C_{70}H_{98}O_{58}$ with a molecular weight of 1,866,784.

Further, Baker and Goodwin [1939] while reviewing the work of various authors have stated that ' Present opinion definitely favours the assumption that pectin is a chain compound composed of galacturonic acid groups......In this chain compound the carboxyl groups are 75 per cent methylated (11·92 per cent CH_3O) and the position of the free carboxyl is arbitrary.'

In rotten fruit proto-pectin disappears, pectin is present to some extent, while pectic acid and methyl alcohol exist in excess. The jellying properties of these are distinctive. Proto-pectin does not form a jelly when cooked with sugar and pectin-free juice. Pectin is the substance to which the jellying of the fruit juice is due. Pectic acid also does not form any jelly, like pectose. Fallenberg [1918] bases the action of various pectic bodies on the methoxy groups which they contain. Sucharipa [1923] carrying out experiments with increased temperature and pressure, obtained pectins of decreased methoxy contents, and the jellying power has been stated to be a direct function of their methoxy contents. This statement is, however, contradicted by Meyers and Baker [1934] who state that 'Contrary to general belief the methoxy content of pectin is not a measure of their jellying power'.

Estimation of pectin by precipitation with alcohol is not reliable. The method of Emmett and Carre [1926] as modified by Nanji and Norman [1928] has been used for the quantitative estimation of pectic substances in the present investigation. The results have been expressed as yield of calcium pectate per 100 gm. of the dried powder of the fruits.

ACID

Cruess and McNair [1916] determined that the optimum acidity of good jellying fruits lay within 0·5—1·5 per cent of acid as citric acid. Campbell [1920] states that 0·3 per cent of acid as sulphuric acid is necessary to produce a good jelly. The presence of 0·86 per cent of sulphuric acid is, in the opinion of Goldthwaite [1918], necessary to produce good jellies from sour apples. Lal Singh [1922] is stated to have made jellies from a mixture of pectin, acid, sugar and water even when it contained as low as 0·05 per cent of citric acid. Tarr [1923] determined a direct relationship with hydrogen ion concentration and formation of jelly, the minimum *p*H being 3·46—a value which is independent of the nature of the acid used. The hypothesis of pectin-acid compound, or the stoichiometric relation between them, finds no substantiation in the works of Gene Spencer [1930] who states that pectin increases the hydrogen ion concentration and does not act as a buffer tending to suppress it, as expressed by Tarr [1923].

SUGAR

Although jellies have been made without any addition of sugar, in general, sugar in the process of jelly making determined the texture, appearance and flavour of the jelly, as well as the yield of the final product. Although sugar can be varied to a great extent for the production of a jelly, but a rather definite proportion of the substance is needed for the formation of a good jelly, and the percentage of sugar existing in the finished product is reasonably constant.

MATERIALS AND METHODS OF ANALYSES

MATERIALS

A brief account of the various materials used in this investigation is given below :—

Feronia elephantum.—Natural Order Rutaceae. Known as elephant or wood apple in English and *Kaitha* in Hindi, is the fruit of a large deciduous tree grown throughout India in great abundance. Its profusion coupled with the great cheapness of the fruit has lowered it in the estimation of the people to such an extent that it is hardly ever eaten by any one. It has, however, been found by the present investigators to be an excellent jelly forming material, being very rich both in acid and pectin. Estimations made at different stages of ripeness of the fruit show that the fruit is most suitable for jelly formation when just ripe.

Psidium guava.—Natural Order Hyrtaceae. Known as guava in English and *Amrud* in Hindi, is a fruit of a low tree, cultivated almost all over India. It is quite rich in pectin, but is incapable of forming jellies as the fruit is deficient in acid. The various varieties grown in India have been classified as Narma, Safeda, Chittidar, Kakra, Karela, Hafni and Seedless, all being well known. Estimations made with each of the above varieties show that Safeda, Chittidar and Kakra varieties are most suitable for jelly making, being richer in pectin than other varieties in their ' just ripe ' and ' fully ripe ' stages.

Carissa carandas.—Natural Order Apocynaceae. Known as *karounda* in Hindi, it is the fruit of a thorny shrub grown throughout India. The fruit is a berry, ½—1 in. long, smooth and reddish purple when ripe. On examination, it has been found to be very rich in acid and pectin, and as such it yields excellent jellies.

Hibiscus sabdariffa.—Natural Order Malvaceae. Known as roselle or red sorrel in English and *patua* in Hindi, is a low shrub that is largely cultivated in India for its pleasant acidulous calyxes during the hot seasons. The red calyx which encloses the entire fruit is very rich in acid and pectin and as such is an excellent source of fruit jellies.

Citrus nobilis Lour.—Natural Order Rutaceae. Known as mandarin in English and *santra* in Hindi, it is the fruit of an evergreen tree of moderate size, grown chiefly in warm and moist regions of India. The fruit has been found to be fairly rich in pectin, but the acid present is not sufficient to form a a good jelly.

Citrus aurantifolia Swingle.—Natural Order Rutaceae. Known as sour lime in English and *nimboo* in Hindi, it is the acid fruit of a low tree which is widely cultivated in many parts of India. It contains 7—8 per cent of citric acid and is very rich in pectin, and forms excellent jellies, which are unfortunately too sour. In view of the fact that the fruit is very rich in acid and pectin its juice is often admixed with other fruit juices which are deficient in them so as to form good mixed jellies.

Zizyphus jujuba.—Natural Order Rhamneae. Known as jujube fruit in English and *ber* in Hindi, it is the fruit of a medium sized tree often found wild and cultivated in many parts of India. The fruit is a drupe, orange or red when ripe, the stone forming 17-20 per cent of the whole fruit. The fruit contains a fair proportion of pectin, but is deficient in acid and only forms good jellies on supplying the extra acid needed.

Musa paradisca.—Natural Order Musaceae. Known as banana in English and *kela* in Hindi, it is the fruit of a tall herb cultivated throughout India for its nutritious and delicious fruit. The peel forms 10-12 per cent of the fruit which is yellow when ripe and green when unripe. The fruit is fairly rich in pectin, but deficient in acid and so does not form any jelly unless extra acid is added.

Aegle marmelos.—Natural Order Rutaceae. Known as *bel* in Hindi, it is the large fruit of a deciduous tree which grows throughout tropical India mainly in the cultivated form. The pulp of the fruit is orange-yellow in colour, many seeded with a transparent and exceedingly sticky gum. It is quite rich in pectin, but very deficient in acid and on that account does not form any jelly unless extra acid is added.

Physalis peruviana.—Natural Order Solanaceae. Known as cape gooseberry in English and *makoi* in Hindi, it is the fruit of a low shrub which is cultivated in many parts of India. The fruit is a berry, which when ripe is of a bright yellow colour enclosed within the membranous calyx which forms 6 to 8 per cent of the whole fruit.

METHODS

The various methods employed for different physico-chemical examinations and in the determination of certain jelly properties are given below :—

1. *Moisture.*—A known weight of the freshly cut fruit was dried to a constant weight in the steam oven, and from this the moisture percentage was calculated.

2. *Pectic substances.*—The quantitative estimation of pectin was made by the method of Nanji and Norman [1928] with certain variations in time and temperature of extraction as given below :—

All enzymes were first destroyed by placing the fresh fruit in thin layers in the steam oven. Thin slices were then cut and dried in enamelled dishes at 92° C. and then ground to a fine uniform powder so as to effect the complete extraction of the pectic substances. As many of the powders were hygroscopic and absorbed moisture from the air rapidly, they were all kept inside a large desiccator.

Equal amounts of each sample (varying between 3 and 5 gm.) were separately extracted with (A) pure water, which removes free pectin, (B) 0·5 per cent oxalic acid solution, which removes pectin and pectose and (C) 0·5 per cent of ammonium oxalate solution, which removes free pectin, pectose and free and combined pectic acid. Extraction was complete after 18 hours' heating at 87°C. The extracts were filtered through fluted filter paper, the residue washed with the same solvent and the total extract and washings made up to 250 c.c., 100 c.c. of each extract were concentrated to 1/3rd the original volume, the extract with oxalic acid solution being neutralized before concentration to avoid hydrolysis. Pectic substances in these extracts, cooled to room temperature were precipitated as usual with acidified alcohol. The alcoholic precipitate after washing free from oxalate was disssolved in water containing a few drops of ammonia, and the pectin estimated in the solution obtained by the usual calcium pectate method. Quantities of pectin, pectose and free and combined pectic acid were calculated from the calcium pectate figures of the three extracts (Appendix, Table I), as under : A=pectin ; B—A=pectose ; C—B=pectic acid, free and combined. At least two and in some cases six to seven samples of fruits were thus estimated for. Total pectic substances (C) has been calculated on 100 gm. of fresh materials, under pectins in Table II given in the appendix. The estimation of pectin in the fruit juice for jelly making has been done as in (A).

3. *Sugars.*—They were estimated as total sugars and reducing sugars expressed in terms of glucose, by the usual Fehling's method.

4. *Acids.*—The total acids have been determined by titration with standard caustic soda solution, expressed in terms of citric acid.

5. *Method of jelly making.*—The best stages of the fruits for jelly making purposes are the just ripe and the well ripe varieties. Their main constituent, responsible for the jelly forming property, is free pectin. It being soluble in water is extracted easily. The pectose present is also hydrolysed to free pectin by the hot extraction usually employed for jelly formation from fruit juices. The clear juice obtained by filtering through a piece of flannel was estimated for its acid and pectin content. Measured volumes of juices were boiled with known amounts of cane sugar in weighed beakers and concentrated to the jelly forming point. The mixture darkened in colour and tended to boil over which was carefully avoided by regulating the flame.

Sheeting test.—A juice rich in acid and pectin begins to jell at 105°C. It has to be concentrated further when the acid and the pectin contents are poor. Another test consisted in taking the hot syrup on the handle of a spatula and allowing it to fall from above. A syrup which would definitely gel on cooling, showed a tendency to break in a ' sheet ' form the edges of the spatula instead of falling in drops. This test recommended by Tarr and Baker [1924] has been used in this investigation. The hot syrup was allowed to cool for 24 hours. The greater the amount of pectin and acid in the finished product, the quicker was the setting point of the jelly.

6. *Determination of jelly strength.*—The thick syrup obtained after testing the jellying point or temperature, was cooled down to 80°C. and then transferred to a weighed Ostwald Viscometer of 3 mm. bore, fitted with a rubber tube and pinchcock arrangement. After setting of the jelly, the rubber tubing was attached to the manometer, which in turn was attached to the suction pump recording an uniform pressure of 20 cm. of mercury. The jelly moved forward steadily and the time it took to go through a particular length of the tube was noted by a stop watch. The times required by different jellies under uniform conditions of experiment are expressed in seconds under the column 'jelly strength'. The ideal jelly required 83 -85 seconds, and 9 seconds indicated a bare gel formation. This method of determination of the relative strengths of jellies was suitable for a fair range of stiffnesses of these materials, but was unsuitable for very tough or sticky jellies.

7. *Determination of sineresis temperature.*—About 5 gm. of the jellies were taken in a test tube and kept in a beaker half filled with water. The

temperature of the water, was raised slowly by a regulated flame, and at the first sign of the formation of drops of clear fluid in the jelly, the temperature was noted. The various temperatures obtained have been tabulated in the column of 'sineresis temperature'. It was found to be 60°C. in the case of good jellies, showing thereby their stability even through the hot months of the year.

SUGAR PECTIN AND ACID RELATIONSHIP IN THE FORMATION OF JELLIES

1. *Effect of sugar.*—With a measured volume of fruit juice, jellies were prepared with increasing amounts of pure crystalline cane sugar. The jelly strength and sineresis temperature were determined. The experimental results obtained with wood apple juice containing 0·238 gm. citric acid and 0·07 gm. pectin (as calcium pectate) are expressed in Table III. Although the quantities of sugar employed varied over a considerable range, the percentage of sugar in the finished jellies was constant within a reasonable limit of error. Jellies made with guava juice containing 0·076 gm. pectin, 0·418 gm. acid and increasing amounts of sugar gave the results expressed in Table IV. Greater yield with decreased toughness in the jellies resulted with increase in the amounts of sugar. The exact amount of sugar necessary for the production of an ideal jelly was also determined. The amounts of acid, pectin and sugar in the finished jelly have also been calculated, indicating the percentage composition of various jellies. Effect of increasing amounts of sugar on roselle juice containing 0·235 gm. acid and 0·12 gm. pectin has also been tried. Table V shows the results. Addition of increased amounts of sugar was continued until the jelly formation was prevented. The failure of jelly formation with a fruit juice even though it may be quite rich in acid and pectin is due to the addition of too much of sugar, which is beyond the holding capacity of the pectin. The importance of such experiments can thus be easily realized, since they indicate the right concentration of sugar for the production of an ideal jelly. Effect of increasing amounts of sugar was also tried with juices obtained from several other Indian fruits like *karounda*, jujube, banana, orange, lemon, *bel* and cape gooseberry, establishing the optimum conditions of their jelly formation.

2. *Effect of acids.*—Normal solutions of citric, tartaric and hydrochloric acids were added in increasing amounts to the same quantity of wood apple juice in different beakers. The percentage of pectin and sugar was kept constant at 0·357 and 59·5 per cent respectively, by adding equal amounts of sugar and boiling the solutions off to a constant weight. Table VI shows the jellies of different strengths thus obtained. It was observed that up to a certain limit, increase of acidity increases the jelly strength. With a further increase of acid, a decrease in the jelly strength resulted, and excess of it produced a syrup which completely failed to jell.

The explanation of the above behaviour is fully borne out by Tarr's [1923] view. He conceives of fruit jellies as possessing theoretically the usual cellulose structure of colloids. The colloid exists in the cell walls in a viscous form and is thereby capable of holding the liquid contents of the jelly up to a certain limit of acidity. The cell walls become firmer and firmer as the acidity is increased, resulting in jellies of greater strength, and also increasing the holding capacity of the cell wall. On increase of acidity beyond a certain limit, the pectin becomes precipitated in the cell wall in a more or less granular form thereby decreasing the liquid retaining properties of the cell walls to a very considerable extent. Under such conditions only syrupy jellies of low strength are obtained. On increasing the acidity still further, even the cell walls become granular and their liquid retaining properties cease altogether. Consequently, no jellies are formed. As to the effect of acids, citric acid produces lesser increase in jelly strength than the same amount of tartaric acid, while only minute quantities of hydrochloric acid were required to produce the same jelly strength.

Similar sets of experiments were performed with guava juice which is quite deficient in acid. Sugar was kept constant at 59·5 per cent and pectin at 0·286 per cent in the finished jelly. Table VII shows the effect. As is clear from the table, at least 7 c.c. of citric acid and 5 c.c. of tartaric acid are required for a distinct jelly, the concentrations in the finished products being 1·46 and 1·02 per cent respectively. Lesser amounts produced only thick syrupy masses. As regards hydrochloric acid, even 0·5 c.c. yielded a product of 67 jelly strength (Table VII), whereas further increase in its amount, in contrast to citric and tartaric acids, tended to decrease the jelly strength with increasing production of bitter taste. Tartaric acid besides being more effective than citric acid, formed jellies with better flavour, texture and colour.

As has been observed above that the increase of acidity increases the jelly strength, with increased acid a decrease in the amount of sugar can be effected to get a jelly of the same strength, and thus 20 per cent sugar has been saved by Lal Singh [1922]. The sugar holding capacity of the pectin also increases with increase of acid, thus resulting in a greater yield of the jelly. Similar experiments were conducted by Tarr [1923] with increased hydrogen ion concentration. The strength of the jelly prepared from a fruit juice was determined. A known amount of tartaric acid was then added to equal quantities of the same juice and the amount of sugar was varied to get a jelly of that very strength. More of acid was added and the corresponding increase in the amount of sugar was determined, till it was found that further increase in acidity did not increase the amount of sugar and if done so, a jelly of lower strength resulted. With 0·095 gm. of pectin in *karounda* juice (Table VIII), 40 gm. of sugar were required at 0·51 per cent acid. On increasing the acidity to 1·6 per cent, the increase in the amount of sugar was found to be 4 gm. Expressing the result with 1 gm. of pectin (as calcium pectate), it could hold 42 gm. of sugar more at 1·6 per cent acidity than what it could at the original acidity. Similarly, guava juice containing 0·134 gm. pectin could hold 30 gm. of sugar (Table IX), but at 2·65 per cent acidity the same amount of pectin could hold 38 gm. of sugar. With 1 gm. of guava pectin, as much as 60 gm. more of sugar can be held at the increased acidity. Similar results were obtained with juices of wood apple and roselle, holding about 70 gm. of sugar more at an acidity of 2·48 per cent. As the tables show, increase of acid increases the percentage of sugar in the finished product. This is due to the greater inversion of the cane sugar, thereby increasing its solubility. Thus more sugar was required to get an approximately saturated solution of it, at which the precipitation of the pectin in the form of jelly occurs. The syrup had to be concentrated further before a tendency to jell was observed.

3. *Effect of pectin.*—Increase of pectin increases the jelly strength and decreases the percentage of sugar at which it begins to jell. Pectin extracted in the usual manner was dissolved in warm water and a concentrated solution obtained. The calcium pectate yield of 10 c.c. of this solution was found out and the solution was used as the source of pectin. The strength of a jelly prepared from a fruit juice was determined and the yield noted. A known volume of the pectin solution was then added to equal quantities of the same juice and the amount of sugar was varied in order to get a jelly of that particular strength. The yield of the jelly was maintained to keep the percentage of the acid constant. Increased volumes of the pectin solution were added and the corresponding decrease in the amount of sugar was determined. Results obtained with wood apple juice are shown in Table X. 10 c.c. of the pectin solution used had a calcium pectate yield of 0·32 gm. 30 gm. of sugar was added to the juice containing 0·07 gm. pectin, when the finished jelly contained 66·6 per cent sugar and 0·16 per cent pectin. On increasing the pectin to 1·57 per cent, the amount of sugar required was only 23 gm. and the finished product contained 51·1 per cent of sugar. On increasing the pectin to 1·93 per cent, the upper layer of the jelly became stiffer and rather bitter showing excess of pectin. It thus appeared that within certain limits, the higher the percentage of pectin in the juice, the lower is the percentage of sugar required to form the jelly. This was well marked till there was about 1·5 per cent of pectin in the jelly, after which further increase of pectin did not decrease the amount of sugar to any great extent. Similar results were obtained from pectin derived from roselle calyx, 10 c.c. of its prepared solution being equivalent to 0·48 gm. calcium pectate . 40 gm. of sugar were needed to produce a jelly with 0·24 per cent of this pectin and the finished product contained 67·8 per cent of sugar. On increasing the pectin to 1·45 per cent, only 53·4 per cent sugar in the finished product was obtained with the same jelly strength. Thus about 15 per cent of the sugar can be saved by increasing the pectin content to 1·5 per cent in the finished jelly (Table XI).

It has been observed in both the above cases that the presence of less than 1·5 per cent of pectin in the jelly showed no distinct taste of the pectin and the jellies were quite normal. When the percentage of pectin was raised further than this point, on the upper part of the jelly, a crust-like formation appeared which was stiffer and less sweet than the lower portion. At about 2 per cent pectin and above, the upper layer besides being more stiff was distinctly bitter in taste, showing that pectin beyond 1·5 per cent (as calcium pectate) remains inactive and undissolved. Lal Singh [1922] observed no change till approximately 2·5 per cent pectin, after which the above abnormality was observed by him. This might be due to the fact that his pectin estimations are expressed in terms of alcohol precipitates which contain many other impurities besides pure pectin.

EXPERIMENTS WITH DIFFERENT KINDS OF FRUITS

Feronia elephantum.—The fruit is an excellent material for jelly making. The inner white pulp attached to the hard rind of the wood apple is also fairly rich in pectin, which can be commercially extracted from it. The method consisted in treating the slices with water or 0·5 per c nt tartaric acid solution and heating for 1½ hours at 90-92°C. The liquid extract was filtered and the residual pulp extracted twice more in the same way. The combined extracts were concentrated and the pectin precipitated with acidified alcohol. It was filtered, washed, dissolved in hot water and reprecipitated with alcohol. The second precipitate was filtered and thoroughly washed. It can be dried by heating under reduced pressure or can be dissolved again in water forming a concentrated pectin solution and stored in bottles for use with fruit juices which are deficient in it.

Psidium guava.—The extraction of fruit juice for jelly making is best effected with 0·5 per cent tartaric acid. In actual experiments extraction done with water yielded 0·72 per cent of pectin, whereas with taratric acid, 1·04 per cent of pectin was extracted, clearly showing its favourable effect. In another experiment jelly was made from guava juice and 0·5 per cent acid, but without any addition of sugar. The resulting product was found to be a very tough dark red jelly. A more interesting experiment made with guava jelly is described below :—

Equal amounts of juice and sugar were boiled off until the temperature reached 105° C. The product being deficient in acid, formed a thick syrup, but no jelly. To each of the beakers normal tartaric acid solution in lots of 5, 10, 15 and 20 c.c. were added in cold. Observations made after 24 hours showed that the beaker containing 20 c.c. of acid had jelled to a fair degree, others to a less extent. After 48 hours fairly stiff jellies were formed in beakers containing 20 and 15 c.c. of acid. That containing 10 c.c. of acid formed a bare gel, whereas no jelly was formed with 5 c.c. of acid. Formation of jellies under such conditions clearly brings out the idea expressed by Tarr and Baker [1924] that precipitation of pectin in the form of jelly occurs in a saturated or nearly saturated solution of sugar, which also seems to be controlled by the active acidity. The greater the amount of acid, the quicker was the precipitation of the pectin in the form of jelly, as observed above. Jellies made at room temperature by Cruess [1922] and Sucharipa [1923] also prove the same interesting fact.

Carissa caraundas.—The fruit being very rich in pectin and acid forms very good jellies. An ideal jelly resulted with juice containing 0·316 gm. acid, 0·072 gm. pectin and 17·5 gm. sugar made in the usual way.

Hibiscus sabdariffa.—Jellies were made out of all the three parts of the fruit. The entire fruit resulted in a jelly which was a little slimy and loose. The fruit pods alone formed a sticky syrup and on addition of acid a bare gel was formed which was also sticky. Jellies made with calyx alone formed very nice jellies of a bright red colour. Analyses of the three parts also showed that the maximum amount of pectin and acid were in the calyx and the least in the fruit pod.

Citrus nobilis Lour.—A sticky mass resulted with the fruit juice and sugar. With gradual addition of acid, jellies of increasing strength were obtained till at 1·7 per cent acid, a fairly stiff jelly resulted, having a good orange flavour.

Citrus aurantifolia Swingle.—Jellies made with the extracted juice and sugar were quite stiff, but the product was too sour and had a slightly bitter taste also The fruit being very rich in acid and pectin is often mixed with other fruit juices deficient in them.

Zizyphus jujuba.—Boiling the fruit juice with sugar resulted in a sticky mass and no jelly. Addition of acid formed the jelly. With low concentration of acid, the jellies were sticky, but the stickness disappeared with increase of acid.

Musa paradisca.—The milky juice extracted from the fruit formed jellies only on the addition of acid and a concentration of 1·7 per cent of acid in the finished product resulted in a fairly stiff jelly. The banana flavour which disappears during boiling is retained by the addition of a few c.c. of concentrated juice at the jellying point.

Aegle marmelos.—The fruit although quite rich in pectin, did not form jelly with increased acid even to the extent of about 2 per cent in the finished product. This is due to the fact that the juice having a peculiar odour, contains excess of a gummy principle which checks the jelly formation. After three days the syrup formed a bare gel which too was very sticky.

Physalis peruviana.—A concentrated extract of the fruit juice with sugar and 1·5 per cent acid resulted in a tender jelly. Efforts to make stiffer jellies failed, as the fruit is poor in both acid and pectin.

Mixed jellies.—Jellies of mixed aroma and flavour resulted by mixing one fruit juice rich in pectin and acid with another having a good flavour. Experiments performed in this way show that four parts of guava and two parts of lemon, five parts of wood apple and one part of lemon, four parts of orange and two parts of wood apple produce ideal jellies, having mixed aroma and flavour.

SUMMARY

1. A quantitative estimation of acids, pectin, sugars and moisture of some Indian fruits has been made, showing their suitability for jelly making.

2. Quantitative estimations of the three pectic substances, namely free pectin, pectose and free and combined pectic acid in the above fruits were made by Nanji and Norman's [1928] method of differential extraction, with certain variations, which greatly diminished the period taken in the estimation.

3. Optimum conditions of formation of jellies from some Indian fruits have been found out, the jelly strength and the temperature of sineresis determined.

4. Effect of mineral and organic acids on the jelly formation has been studied. Increase of acidity increases the jelly strength to a certain limit, after which it is decreased. The sugar holding capacity of pectin increases considerably by increase of acid, and tartaric acid has been found to be more effective than citric acid in this respect, besides producing a better flavour.

5. Increase of pectin decreases the percentage of sugar at which the syrup begins to jell, but increase of pectin beyond 1·5 per cent in the finished product remains inactive and undissolved, resulting in abnormal jellies with somewhat bitter flavour.

6. A definite amount of sugar is required for a particular juice to result in an ideal jelly depending upon its acid and pectin contents, and a definite equilibrium exists between sugar, acid, pectin and water when jelly formation occurs.

7. The percentage composition of ideal jellies lies between 65 and 70 per cent total solids, containing 0·75—1·75 per cent acid as citric acid, 0·25—0·5 per cent of pectin as calcium pectate and 61—65 per cent of sugar.

8. Employing total acidity as the criterion of the acid content of a frut jelly, substantiation of the theory put forward by Tarr and Baker [1924] has been made, which states that a fruit jelly formation appears to be a precipitation of pectin in approximately saturated solution of sugar, and this seems to be controlled by active acidity.

REFERENCES

Baker, G. L. and Goodwin, M. W. (1939). *Univ. Delaware Agric. Expt. Sta. Bull. No.* **216**, *Tech. No.* **23**

Branfoot, M. H. (Carre) (1929). *A critical and historical study of the pectic substances of plants : Dept. Sci. & Ind. Research Sp. Report. No.* **33** *(London)*

Cruess, W. V. and Lal Singh (1922). *Calf. Expt. Sta. Cir.* **243**

Cruess, W. V. (1938). *Commercial fruit and vegetable products*

Doree, C. (1933). *Methods of cellulose chemistry*

Hass, and Hill, (1921). *Chemistry of plant products*

Hunt, S. W. (1939). *Chemistry in Commerce*

Lal Singh and Lal, G. (1938). *Studies in the preservation of fruit juices : Indian J. agric. Sci.* **8**

Lal Singh (1922). *Canning Age, June, July and August Nos.*

Meyrs, P. B. and Baker, G. L. (1934). *Univ. Delaware Agric. Expt. Sta. Bull. No.* **187**, *Tech. No.* **15**

Mitra S. K. (1931). *Canning and preserving*

Morris T. N. (1933). *Principles of fruit preservation*

Nanji, D. R. and Norman, A. G. (1928). *The estimation of individual pectic substances in nature : Bio-Chem. J.* **22**, 596

Onslow, M. W. (1929). *Practical plant biochemistry*

Spencer, G. (1930, 1). *Relation between acid and pectin to jelly formation : J. Phys. Chem.* **1**, 410

——— (1930, 2). *Purification and estimation of pectin : J. Phys. Chem.* **1**, 429

——— (1930, 3). *Measurement of jelly strength : J. Phys. Chem.* **1**, 654

Tarr. L. W. (1923). *Fruit jellies : Univ. Delaware Expt. Bull. No.* **134**, 2

Tarr, L. W. and Baker, G. L. (1924). *Univ. Delaware Expt. Sta. Bull. No.* **136**, 3

APPENDIX

TABLE I

Estimation of pectins

(Percentage of pectic substances in the dried powder of the fruits)

Fruit	A (water)	B (oxalic (acid)	C (Ammonium oxalate)	B-A	C-B
Wood apple—					
A. Pulp . . .	10·54	12·95	14·05	2·41	1·1
B. White peel . .	9·75	14·15	19·2	4·4	5·05
Guava	4·26	6·08	6·89	1·82	0·81
Karaunda . . .	5·41	9·16	11·24	3·75	2·08
Roselle—					
A. Calyx . . .	17·52	23·25	27·1	5·73	4·05
B. Entire fruit . .	9·52	13·15	14·35	3·63	1·2
C. Fruit. . . .	3·12	4·05	4·31	0·93	0·26
Orange	8·85	10·7	11·85	1·85	1·15
Lemon	13·65	17·14	18·55	3·49	1·41
Jujube (*ber*) . . .	3·9	6·52	7·28	2·62	0·76
Banana	2·52	3·2	4·53	0·68	1·33
Bel	2·75	4·6	6·57	1·85	1·97
Cape gooseberry . .	2·05	4·25	4·65	2·2	0·4

TABLE II

Analyses of fruits

(Figures indicate percentage of various components in fresh fruits)

Fruit	Acid	Pectins	Total sugars	Reducing sugars	Moisture
Wood apple . . .	3·72	3·95	6·86	4·51	71·8
Guava	0·32	1·44	16·62	6·12	78·8
Karaunda . . .	3·1	1·23	2·23	1·22	89·0
Roselle—					
A. Calyx . . .	3·74	3·19	3·34	2·41	88·2
B. Entire fruit . .	2·05	2·48	3·1	1·22	82·66
C. Fruit. . . .	1·03	1·02	2·28	1·05	76·4
Orange	1·17	1·2	11·53	5·4	88·6
Lemon	7·47	2·76	0·84	. .	85·08
Jujube (*ber*) . . .	1·12	1·45	15·78	7·23	80·01
Banana	0·3	1·19	19·98	6·78	73·6
Bel	0·51	2·03	13·04	5·26	68·8
Cape gooseberry . .	2·19	0·75	15·56	6·78	83·8

TABLE III

Effect of sugar

[On wood apple juice containing 0·238 gm. acid (citric) and 0·07 gm. pectin (calcium pectate)]

Sugar added in gm.	Yield of jelly (gm.)	Jelly strength	Sineresis temperature (°C.)	Percentage of acid	Percentage of pectin	Percentage of sugar
10	16·5	120	64·5	1·44	0·42	60·5
12·5	20·5	84	61	1·11	0·34	61
15	24	75	56	0·95	0·29	62·5
20	31·6	70	50	0·75	0·22	63·2
30	47	27	41·5	0·50	0·15	63·83
40	63·8	13	34	0·37	0·11	64·2
50	77·2	9	Room temp.	0·31	0·09	64·7

TABLE IV

Effect of sugar

[On guava juice containing 0·418 gm. acid (citric) and 0.076 gm. pectin (calcium pectate)]

Sugar added in gm.	Yield of jelly (gm.)	Jelly strength	Sineresis temp. (°C.)	Acid (per cent)	Pectin (per cent)	Sugar (per cent)
10	16·5	180	66	2·53	0·46	60·5
15	24	85	60·5	1·74	0·32	62·5
20	32	74	52·5	1·3	0·24	62·5
30	47	62	47	0·89	0·16	63·8
40	62·5	12	32	0·67	0·12	64
45	70	9	Room temp.	0·59	0·11	64·3
50	77·5	No gel	..	0·45	0·09	64·5

TABLE V

Effect of sugar

On roselle juice containing 0·235 gm. acid (citric) and 0·12 gm. pectin (calcium pectate)]

Sugar added in gm.	Yield of jelly (gm.)	Jelly strength	Sineresis temperature (°C.)	Acid (per cent)	Pectin (per cent)	Sugar (per cent)
10	16·5	210	72	1·43	0·73	60·5
15	24·5	105	65	0·96	0·49	61·2
20	32·2	83	62	0·73	0·37	62·1
25	39·7	32	43	0·59	0·30	63·0
30	47·4	15	36·5	0·49	0·26	63·4
35	55	9	Room temp.	0·42	0·22	63·7
40	62·5	No gel	..	0·37	0·19	64·1

TABLE VI

Effect of acids

(Figures indicate the strength of the wood apple jellies obtained, containing 59·5 per cent sugar and 0·357 per cent pectin)

Normal solution in c.c. added	Citric acid	Tartaric acid	Hydrochloric acid
0·5	58	61	76
1	65	70	70
2	70	76	42
3	73	84	10
5	80	75	No gel
7	72	67	..
10	58	45	..

TABLE VII

Effect of acids

(Figures indicate the strength of guava jellies obtained, containing 59.5 per cent sugar and 0·286 per cent pectin)

Normal solution in c.c. added	Citric acid	Tartaric acid	Hydrochloric acid
0.5	No gel	No gel	67
1	,,	,,	53
2	,,	,,	32
3	,,	,,	11
5	,,	12	9
7	14	48	No gel
10	42	55	..
15	56	72	..
20	70	64	..
25	54	42	..

TABLE VIII

Effect of acids

[Showing the sugar-holding capacity of *Karounda* pectin (0·095 gm.) with increased acidity]

Acid added in gm.	Sugar required (gm.)	Yield of jelly (gm.)	Percentage of acid	Percentage of sugar
None	40	62·7	0·51	63·7
0·25	42	65·4	0·87	64·2
0·5	43	66·1	1·24	65·05
0·75	44	66·8	1·6	65·8
1·0	44	66·2	1·99	66·4

TABLE IX

Effect of acids

[Showing the sugar-holding capacity of guava pectin (0·134 gm.) with increased acidity]

Acid added in gm.	Sugar required (gm.)	Yield of jelly (gm.)	Percentage of acid	Percentage of sugar
0·25	30	46·5	0·63	64·5
0·5	32	49·3	1·1	64·9
0·75	35	54·2	1·46	64·6
1·0	37	56·8	1·8	65·1
1·5	38	58·1	2·65	65·4

TABLE X

Effect of pectin

(Showing decrease in the amount of sugar with increase of wood apple pectin solution)

Pectin solution added in c.c.	Total amount of pectin (gm.)	Sugar required (gm.)	Percentage of pectin	Percentage of sugar
None	0·07	30	0·16	66·6
5	0·23	27·5	0·51	61
10	0·39	25·5	0·86	57
15	0·55	24	1·22	53·3
20	0·71	23	1·57	51·1
25	0·87	22·5	1·93	50
30	1·03	22	2·28	48·8

TABLE XI

Effect of pectin

(Showing decrease in the amount of sugar with increase of pectin from roselle calyx)

Pectin solution added (c.c.)	Total pectin (gm.)	Sugar required (gm.)	Percentege of pectin	Percentage of sugar
None	0·14	40	0·24	67·8
5	0·38	36·5	0·64	61·8
10	0·62	33·5	1·05	56·7
15	0·86	31·5	1·45	53·4
20	1·10	30	1·86	50·1
25	1·34	29	2·27	49·1
30	1·58	28·5	2·67	48.3

NOTE

BIOLOGICAL CONTROL OF LANTANA

LANTANA, originally considered as an ornamental plant, has assumed the status of a noxious weed in several parts of the world, including India. The Forest Departments in India are generally agreed that it is a weed with no prospects of economical utilization and should, if possible, be replaced by tree crops.

Several attempts have been made to exterminate the weed by biological methods of control in various parts of the world. The bug *Teleonemia lantanæ* Distant (=*T. scrupulosa* Stal) has proved most promising from this view-point. This bug was introduced into Hawaii, Australia, Fiji, etc. for the control of lantana and has proved most useful in Australia. It is probable that in one or more of the climatic regions in south India the bug will flourish, but it perhaps cannot be relied upon to produce wholesale destruction of the weed throughout India. In this connection, it should be remembered that the family *Verbanaceæ*, which includes lantana, also includes teak and several plants, e.g. *Verbena*, *Vitex negunda*, *Aloysia citrioldora*, species of *Clerodendron*, which are ornamental plants in India. This bug has been found to attack *Callirhœ involucrata* and an undetermined species of Labiatæ in some parts of the world.

Thus the bug has potentialities for evil also. One has to be sure that by introducing an undesirable lantana insect a problem more difficult to solve than the extermination of lantana itself is not created. One should not go by what plants are known to be attacked by this insect in other parts of the world, but should determine for oneself what it would attack in India. Almost every important country, which introduced this bug, did so after exhaustive tests on economic plants under quarantine conditions. The Forest Entomologist, Forest Research Institute, Dehra Dun, is investigating the capabilities of the bug. In the meantime, the Government of India have notified Provincial Governments not to release the insect *Teleonemia lantanae* for the control of lantana weed till the characteristics of the insect have been more fully investigated, and not without the fullest consultation with the expert authorities, especially the Forest Entomologist, Forest Research Institute and College, Dehra Dun, and the Imperial Entomologist, Imperial Agricultural Research Institute, New Delhi.

REVIEW

Deltaic Formation. By C. Strickland (Longmans, Green & Co. Ltd., 1940. Pp. 158 : Rs. 5)

PROFESSOR Debenham writes in the foreword : 'It is unusual but not unique to find an expert in one branch of science applying himself to problems in another branch removed from his own. The result often is that new light is thrown upon the subject, viewed as it must be from an aspect totally different to that used by its own specialists. ....Naturally his terminology and his metaphor are unusual, but that should not prevent the reader from understanding the author's outlook.' And Dr Cyril Fox in his introduction joins issue with the author regarding the correctness of the term Ganges Delta and states : 'The Ganges Delta on the other head represents so much country so to speak abandoned by this great river as it has adopted new channels from its original course down the Hughli to its present junction with the new Brahmaputra. The latter river also does not give off any actual distributaries.' But concludes,' However, while I may argue about the correctness of the term Ganges Delta there can be no doubt of its mode of formation which Dr Strickland describes so fully .'

The book is based on personal knowledge acquired in course of tours and travels in connection with the author's study of the conditions and circumstances under which malaria develops and thrives. As he tells us in the preface the book is 'a contribution to physiography not only for the use of those engaged in the prevention of malaria in the tropics but also for that of other administrators such as those who have to deal with irrigation, agricultural science, forests, land-settlement town-planning, water supplies, port and river conservancy, rural sanitation, road and railway construction, bridge building and in fact those who should base their schemes on a succinct knowledge of what Nature is doing under their very noses.' The reviewer fully subscribes to the view that correct and more complete knowledge of this region will be of immense public benefit. Schemes of public utility, if they are to be sound and fruitful, have to be based on the results of scientific enquiry. It cannot be denied, however, that the problems confronting such enquiries require the attention of experts in several branches of science and perhaps the very best of them. River physics is a very specialized branch of study, so also is the problem of soil genesis. It is on the facts ascertained by physicists, river engineers, geologists and soil scientists and, though it may not be so apparent, by botanists and zoologists that the geographer has to base his thesis and his correlated general picture of the geographical features of a region.

The quotations given above explain the scope and interest of this book. The detailed scientific study of the Lower Bengal has, however, scarcely begun, although in addition to its practical interest a full knowledge of its past and present conditions is of general scientific interest.

Dr Strickland has undoubtedly earned the thanks of all interested in the Ganges delta in undertaking the task of writing this interesting book on the manner of formation of this region and thereby stimulating thought and attention to a scientific study of this region. The state and the public have definitely a duty to perform in fostering such studies and should not leave them to the offchance of an enthusiast undertaking this work who, however qualified he may be, can scarcely encompass the whole field of enquiry or gather the basic data unaided by a body of experts in allied fields and within a reasonable interval of time.

The book is divided into 27 chapters dealing with various subjects including the following :

Scope of the enquiry ; what is meant by a 'Delta' ; the birth and infancy of the land ; a digression on alluvial fans ; floods ; the flood-plain ; land and water profiles in relation to the tides ; ground and surface water ; seepage ; varying character of the sedimentation and stratification ; meandering ; *bhils* and *jheels* ; salinity of the rivers of the Delta ; and the influence of diastrophism of the Earth's crust on the hydrographic processes.

His main thesis appears to be as follows : Only hydrographic processes as opposed to diastrophic processes are responsible for the formation of the Ganges delta and the *bhils*, lakes, alluvial fans and others which occur in this region. Hydrographic processes are of course major contributory factors to the formation of deltaic tracts but he denies, particularly with regard to Bengal Delta, the influence of diastrophic changes suggested by some geologists and geodesists. In order to settle this controversial question it seems necessary to make deep borings similar to that put down at Fort William in Calcutta in 1919 in various regions with a view to examining in detail the nature of the deposits. This work, however, involves considerable expense. The available data are not sufficient to fully support the author's contentions mentioned above and the following observations illustrate the difficulties which the reviewer has felt in accepting them.

1. It is rather doubtful that the 'swatch-of-no-ground', a deep chasm of the size and shape found at the head of the Bay of Bengal would be formed merely by hydrographic processes. The author does not attempt to indicate how the magnitude of the forces which are involved can be produced by hydrographic factors of the type consiered by the author. To the reviewer diastrophic changes appear to offer a more correct explanation. (2) The author's characterization of a 'delta' as 'depositing' and of 'paradelta' as 'eroding' does not seem to have much significance. Is it not an usual occurrence that rivers erode one bank and lay deposits on the other or swing from position to position or change their course as a result of erosion and deposition ? What part do the variations in the rainfall and the run-off to rivers play in affecting the course of rivers ? Or in other words, does the 'degrading' and 'aggrading' action of a river work so smoothly through geological periods of time ? (3) According to the author the Madhupur Jungle tract, the Barind of North Bengal, the red bank of Comilla, etc. are nothing but terraces of old deposits of glacial origin that have so far escaped degradation by the erosive action of the Ganges, its tributaries and distributaries. Ordinarily the erosive action of rivers is weakest towards the sea face and greatest upwards. The relative sizes of the residual masses of land comprising these

tracts are, however, contrary to what is expected from the above consideration. More concrete data regarding the courses of the rivers at various times, and the geology of the land masses are required for critical correlation. (4) The processes discussed by the author of the formation of *bhils* in the Lower Bengal appears to be suggestive. But ephemeral changes to which the author refers in the last chapter and which mask the effects of secular variations might be as well caused by very weak crustal movements.

In connection with a soil survey in the coastal regions of the Bakharganj district, the reviewer had occasion to visit some of these tracts, which comprise recent *char* land and lands formed about 150-200 years back. They lie somewhat inland about 40 miles from the sea and are formed by the deposition of the large volume of suspended matter carried by the rivers. No evidence has been obtained of the type of aggrading or degrading action mentioned by the author. By means of profile examination together with physical and chemical analyses it has been possible to obtain a general picture of the formation of these tracts. The deposits consist of layers about 2-3 mm. thick of clay and silt separated by almost a unigranular deposit of fine sand or material of coarser texture. These 'horizons' in the soil profile have been termed 'deposition horizons' which are shown very clearly by recently formed *chars*. From the number of such layers it seems possible to count the number of tidal flows and ebbs which produce a given depth of the soil. Although unusual floods leave their mark on the whole profile, the process of formation of the soil suggested by these 'deposition horizons' is very uniform over this tract. In older *char* lands the top deposits are disturbed through cultivation and other influences. These interferences during the raising of the land tend to form a hard subsoil layer by the accumulation of finer particles, e.g., clay and silt. This is probably the origin of 'clay pans' in the coastal areas, which have been observed so far in the older *chars*.

As already mentioned the study of the formation of this deltaic tract should be placed on a more scientific basis. For this it seems that deep borings and analyses of the deposits at different depths by mineralogical, physical and chemical methods would throw considerable light on the nature of the deposits, the manner of transport and the mode of formation of the tract.

The book is generally free from printing and other errors. A few which caught the reviewer's eyes are mentioned below :

(1) 'Madaripur Jungle' in the map on page 9 should be 'Madhupur Jungle'.

(2) There is no reference to 'swatch-of-no-ground' on page 9, although the index mentions this ; the reference is perhaps to page 12, of which the index, however, makes no mention.

(3) 'Indeed it has been elsewhere stated that his (Rennel's) survey ....methods' (page 118). No such reference is to be found in the book. [J. N. M.]

PLANT QUARANTINE NOTIFICATIONS

The Imperial Agricultural Bureaux have just issued the 10-year Subject and Author Index to *Horticultural Abstracts* 1931-40. Price about 25*s*. (No free issue.)

All orders should be sent direct to The Imperial Agricultural Bureaux, Central Sales Branch, Agricultural Research Building, Penglais, Aberystwyth, Wales

INDIA

Form of special permit authorizing importation of insects

[Prescribed by the Central Government under para. 2(*a*) of the Notification* No. F.-193/40-A, dated 3 February 1941]

1. Name, designation and full address of the importer . . . .
2. Name of the insect species to be imported . . . .
3. Stage or states of the insect to be imported . . . .
4. Country from which importation is sought . . . .
5. Whether importation is intended by sea, land or air . . . .
6. Whether in its original home it is a weed pest, a parasite or a predator. ....
    - (*i*) Name (names) of the weed (weeds) on which it is a pest in the country of origin . ...
    - (*ii*) Name (names) of the pest (pests) on which it is a parasite or predator in the country of origin . . . .
7. Name, designation and address of the exporter . . . .
8. Quantity indented for . . . .
9. Purpose of importation . . . .

I authorize the importation. This permit will be valid up to..........
....

(Signature and designation of the
certifying authority)

Date...................

[*N.B.*—It is expected that the permit will be obtained in advance of sending the order so that the imported material may not remain indefinitely in the warehouse for want of suitable permit.]

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*Published in this Journal, Vol. 11, Part II, page 322

Notification No. F. 193/40-A. (c), dated 12 August 1941 of the Government of India in the Department of Education, Health and Lands

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following amendment shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F.-193/40-A., dated the 3rd February 1941, namely :—

> In clause (*b*) of paragraph 3 of the said Order, after the word ' Orissa ' the words ' Jammu and Kashmir ' shall be inserted.

G. S. BOZMAN

Joint Secretary to the Government of India

Notification No. F. 15-11/41-A., dated 1 September 1941 of the Government of India in the Department of Education, Health and Lands

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendment shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320-35-A., dated the 20th July 1936, namely :—

> In sub-paragraph (2) of paragraph 9 of the said Order for the words and brackets ' (*Ceratostomela paradoxa* or *Thielaviopsis paradoxa*) ' the words and brackets ' *Ceratostomella paradoxa* (Thielaviopsis paradoxa) ' shall be substituted.

G. S. BOZMAN

Joint Secretary to the Government of India.

CORRIGENDA

THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE, VOL. 11, PART IV

Page 543 (appendix), column 3, line 10, *for* ' 16,500·0 ' *read* ' 116,500·0 '

Plates XXVI and XXIX illustrating the article ' The Description of Crop-plant Characters and their Ranges of Variation, III. The Variability of India Wheats ' differ from the originals in colour reproduction. Research workers who wish to use the colour grades recommended in the above-mentioned article may apply to the Imperial Economic Botanist, Imperial Agricultural Research Institute, New Delhi, for more accurate copies of the original plates made by an artist.

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